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El Niño in Peru: Biology and Culture Over 10,000 Years

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Title-page illustration: Moche fineline painting from northern Peru showing a naturalistic figure in an animated reed boat. The drawing is by Donna McClelland and is reproduced from *Moche Fineline Painting: Its Evolution and Its Artists* (UCLA Fowler Museum of Cultural History, 1999) courtesy of the artist, the authors, Christopher Donnan and Donna McClelland, and the publisher. The vessel from which the drawing was made is in the collections of the Art Institute of Chicago.

Introduction

On May 28–29, 1999, a group of sixteen scientists met at the Field Museum in conjunction with the VIII Annual A. Watson Armour III Spring Symposium to discuss the impacts of the El Niño phenomenon on the biology and cultural history of coastal Peru over the last 10,000 years. The meeting brought together anthropologists, archaeologists, and biologists with a shared interest in the effects of this potent global weather disturbance. The one-day workshop and subsequent symposium presented research results documenting the impact of this phenomenon from a wide range of perspectives. The papers published here represent the results of research from these various fields and differing points of view. The impact of El Niño on terrestrial and marine ecosystems has been well documented over the last 20 years, but the interpretation of these results remains controversial. The common thread linking most of these efforts is an attempt to date the onset of the El Niño phenomenon using various types of proxy data. Estimates range from a few thousand to tens of thousands of years. Whatever its age, it is obvious that El Niño had and continues to have a profound impact on the coastal environments of Peru, and more generally of western South America.

Michael O. Dillon

1

The *Lomas* Formations of Coastal Peru: Composition and Biogeographic History

Michael O. Dillon, Miyuki Nakazawa, and Segundo Leiva Gonzáles

For nearly 3,500 km along the western coast of South America (5°–30°S latitude), the Atacama and Peruvian deserts form a continuous hyperarid belt, broken only by occasional river valleys from the Andean Cordillera. Native vegetation of the deserts is largely restricted to a series of fog-dependent communities termed *lomas* formations, meaning small mountains. This chapter provides a backdrop for the subsequent discussions in this volume of human occupation in coastal Peru over the last 10,000 years. This requires a synthesis of the present-day coastal vegetation, analysis of the origins of the modern flora, and reconstruction of past climates, including the onset of El Niño conditions, using proxy data from a variety of sources. Paleoclimatic data suggest that arid conditions existed along the coast prior to 100,000 years ago, well before the arrival of the first humans in western South America. Distributional patterns and relationships within specific members of the flora are discussed to help explain current conditions. Specifically, we have examined relationships in the flowering plant genus *Nolana* (Solanaceae), a group of over 80 species distributed predominantly in the *lomas* formations of Peru and Chile. The reconstructed phylogeny of *Nolana* provides a framework for examining the coastal *lomas* formations and the processes important in their evolution, including the effects of glacial cycles, sea level changes, and the historical development of the El Niño–Southern Oscillation weather phenomenon.

Introduction

Much of the western coast of South America (5°–30°S latitude) is occupied by deserts, forming a continuous belt that extends for more than 3,500 km along the western escarpment of the Andean Cordillera, from northern Peru to northernmost Chile. The climate and geomorphology of this region have been discussed in detail elsewhere (Dillon 1997; Ferreyra 1953; Rundel et al. 1991), and only a brief sketch is provided here for discussion purposes. The Peruvian desert is a narrow coastal band at the base of the Andean Cordillera that extends nearly 2,000 km in length but is only 50–100 km wide. The desert is interrupted only by occasional rivers that reach the coast, and their borders support riparian vegetation common to the inland river valleys. The factors responsible for the development of the hyperarid conditions include isolation from eastern weather patterns by the Andean Cordillera, and temperature homogeneity resulting from the influence of cool sea-surface temperatures associated with the south-to-north flow of the Humboldt (Peruvian) Current. This, combined with a positionally stable subtropical anticyclone, results in a mild, uniform coastal climate with the regular formation of thick fogs below 1000 m elevation from September to December.

Where the coastal topography is low and flat, this stratus layer dissipates inward with little biological impact (Figs. 1 and 2A), but where isolated mountains or steep coastal slopes intercept

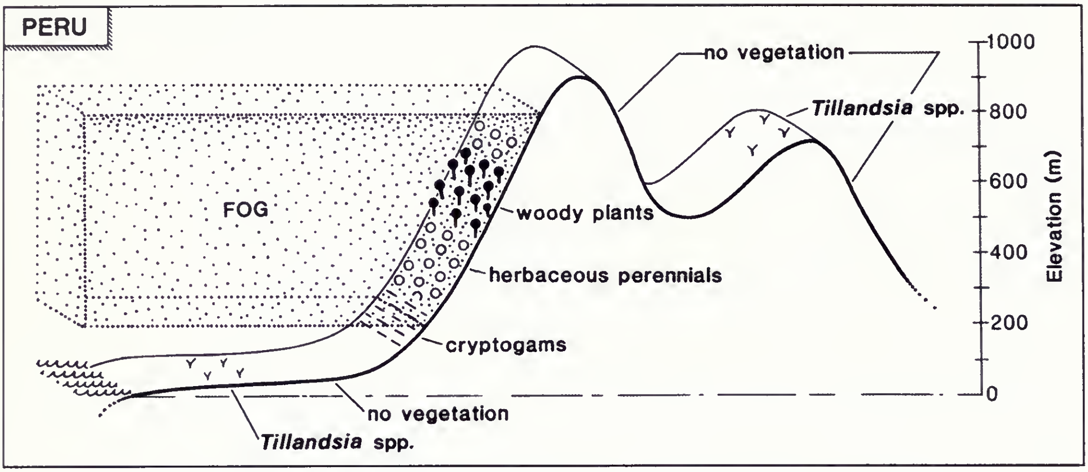


Figure 1. Vegetation zonation in the fog zone or *lomas* formation of coastal Peru.

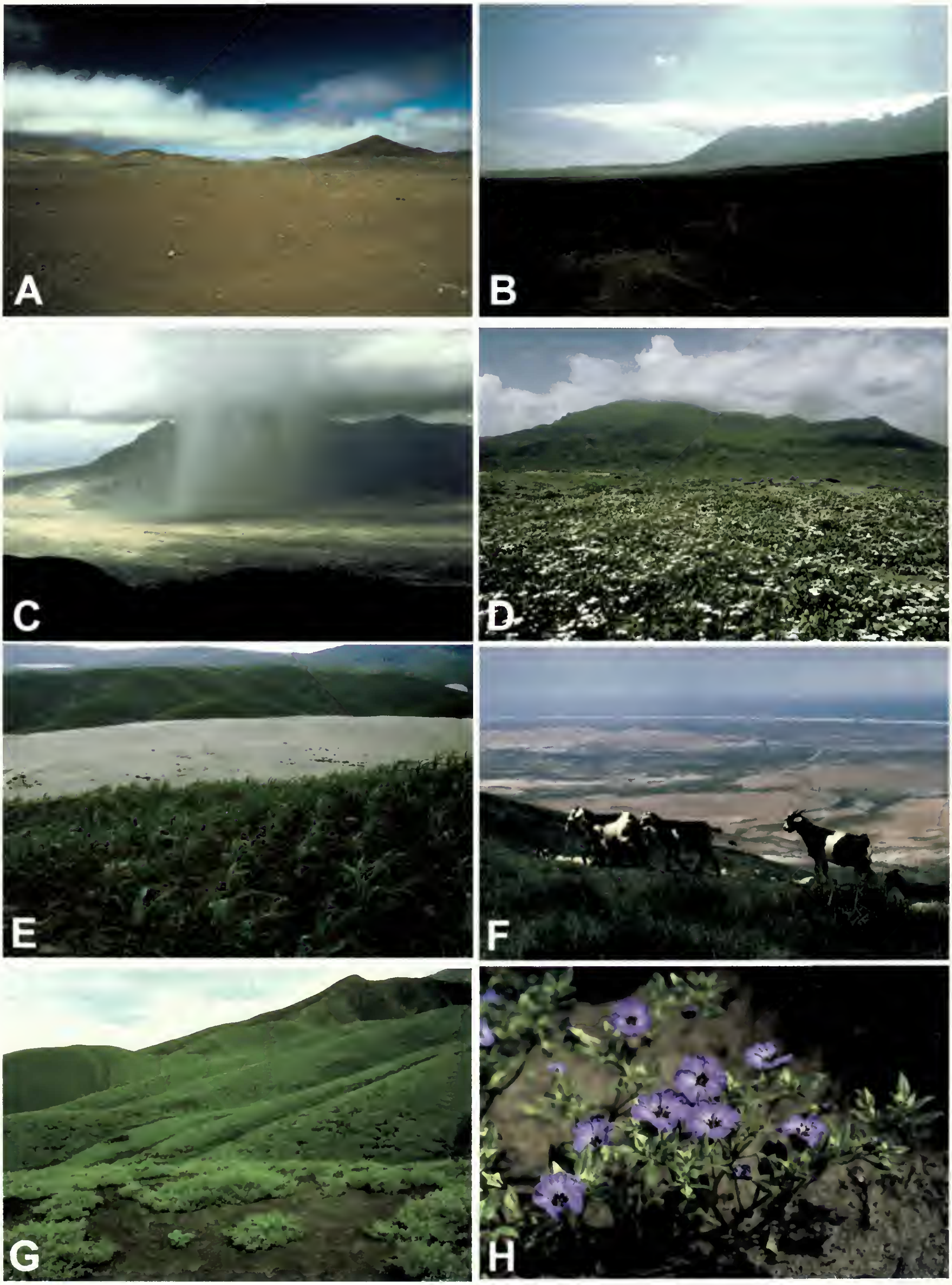
the clouds, a fog zone develops with a stratus layer concentrated against the hillsides (Fig. 2B). This fog, termed *garúa* in Peru, is key to the floristic diversity of the unusual desert plant communities, termed *lomas* formations. In Peru, we estimate there are nearly 70 discrete localities supporting *lomas* vegetation (Fig. 3), including several offshore islands (e.g., Islas de Las Viejas, San Gallán, San Lorenzo). The actual area covered by vegetation, even during periods of maximum development, is probably less than 8,000 hectares. The vegetation of the *lomas* formations of Peru is unique and composed of many species that occur only in these small desert oases.

Lomas Vegetation

Lomas communities occur as islands of vegetation separated by varying distances of hyperarid habitat devoid of plant life. Since plant growth is dependent on available moisture and the drought tolerance of individual species, a combination of climate, physical topology, and the ecophysiology of each species of plant ultimately determines community composition. The individual formations are highly variable and consist of mixtures of annuals, short-lived perennials, and woody vegetation. Current estimates of the flora of the Peruvian *lomas* include over 815 species distributed in 357 genera and 85 families of flowering plants. The distribution patterns of these species can be roughly grouped into broad categories, including (1) pan-tropical or weedy species, (2) long-distance disjunctions from the Sonora Desert or Baja California, (3) species disjunct from the adjacent Andean Cordillera, and (4) plants restricted to the coastal deserts, sometimes in a single locality. Endemism at the level of species often exceeds 40% in individual *lomas* communities. The greatest number of endemics are found in southern Peru between 15°S and 18°S latitude and include both endemic genera, such as *Islaya* (Cactaceae), *Weberbaueriella* (Fabaceae), *Mathewsia,* and *Dictyophragmus* (both Brassicaceae), and endemic species within genera, such as *Ambrosia* (Asteraceae), *Argylia* (Bignoniaceae), *Astragalus* (Fabaceae), *Cristaria* and *Palaua* (both Malvaceae), *Calceolaria*

→

Figure 2. Atacama and Peruvian desert communities. **A.** Flat inland desert region devoid of plants. **B.** Stratus clouds impacting the headlands where *lomas* formations develop. **C.** Rainstorm above Cerro Campana in the northern Peruvian coastal desert during the 1997–1998 El Niño event, February 1998. **D.** Cerro Cabezón during the 1997–1998 event. **E.** Corn cultivated within the *lomas* formations of Cerro Cabezón in northern Peru, January 1998. **F.** Goats grazing on the abundant vegetation at Mejía during the El Niño event, October 1983. **G.** A carpet of *Nolana humifusa* on the upper slopes of Cerro Cabezón, January 1998. **H.** Flowering individual of *Nolana humifusa* at Cerro Cabezón.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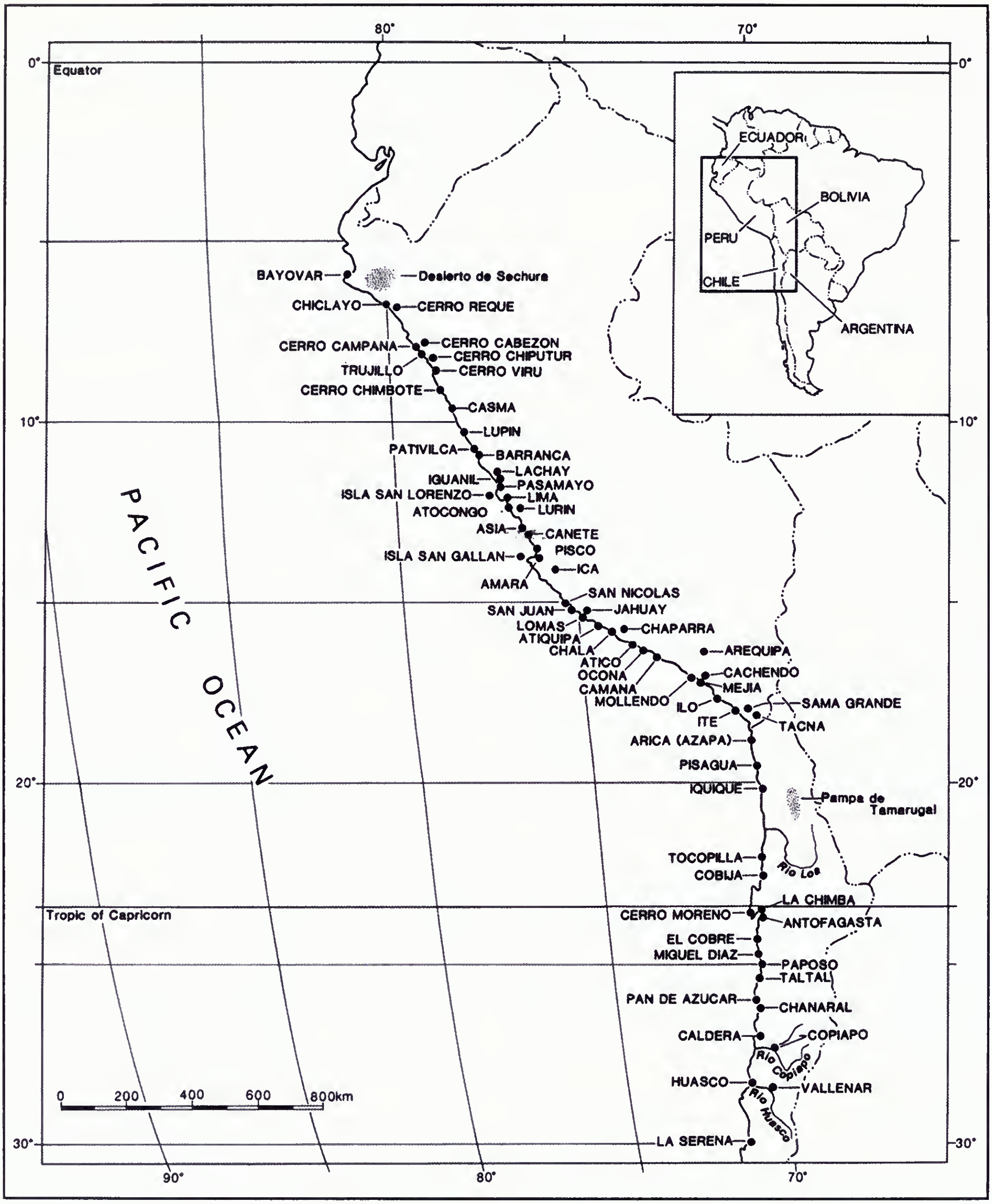

Figure 3. Geographic features, including *lomas* formation localities, in the Atacama and Peruvian deserts.

(Scrophulariaceae), *Tiquilia* (Boraginaceae), *Jaltomata, Leptoglossis,* and *Nolana* (all Solanaceae), and *Eremocharis* (Apiaceae).

We have examined patterns of similarity within the overall flora of the *lomas* formations and have found that the coastal deserts of western South America are not uniform (Duncan and Dillon 1991; Rundel and Dillon 1998; Rundel et al. 1991). Our analysis supports three floristic segments that appear to have independent histories: (1) a northern Peruvian unit from 7°55′S to 12°S latitude, (2) a southern Peruvian unit from 12°S to 18°S latitude, and (3) a northern Chilean unit from 20°S to 28°S. The area between 18°S and 20°S is nearly devoid of vegetation (Rundel et al. 1991) and is suggested to have been a barrier to coastal dispersal for an extended period (Alpers and Brimhall 1988). Only 115 species, or ca. 12% of the total desert flora of 1,350 vascular plant species, are recorded from both sides of 18°S (roughly the Peru–Chile border). When widespread weeds are eliminated from that total, less than 6% of the native species are known from either side.

Although the richness of the marine environment would have provided early man with a primary source of sustenance (Keefer et al. 1998), the *lomas* formations could also have acted as an important source of fresh water, food, and construction materials for early coastal visitors and inhabitants (Lanning 1965). The presence of vegetation, often forageable, would have attracted the native camelids, for example, *guanaco,* and deer, both of which were game for early man. Supplies of seeds and insects would have made *lomas* sites havens for native bird species. The native flora does contain some edible fruits; for example, *Jaltomata* and *Lycopersicon,* both members of the Solanaceae family, have tomato-like, edible berries. Edible roots from diverse plant families might also have provided some nourishment that could have been utilized periodically, for example, *Argylia radiata* (Bignoniaceae), *Begonia octopetala* (Begoniaceae), *Oxalis dombeii* (Oxalidaceae), *Solanum montanum* (Solanaceae), and *Tropaeolum peltophorum* (Tropaeolaceae). Agriculture may also have been practiced at some locations, especially during exceptional years associated with El Niño events. Today, crops are cultivated in the *lomas* formations when opportunities are provided by increased available moisture. Corn was planted at Cerro Cabezón (Fig. 2E) in northern Peru during an El Niño event in March 1998, and both corn and wheat were cultivated in the *lomas* between Moquegua and Tacna in 1983.

The influence of man on the *lomas* formations, especially over the last 1500 years, should not be underestimated. Many native woody species have been severely depleted for firewood and construction. It may be assumed that native tree species, such as *Caesalpinia spinosa* (*tara*), *Carica candicans* (*mito*), or *Myrcianthes ferreyrae,* had wider distributions and larger populations prior to the arrival of man. The removal of woody vegetation almost certainly would have changed the extent of herbaceous plants. Building in many coastal areas has replaced *lomas* habitat with homes and factories. Movement of livestock between the interior and the coast has led to the introduction of many Andean weeds (Sagástegui and Leiva 1993). The historical introduction of alien or exotic species, such as Australian trees (*Eucalyptus* and *Casuarina*), has changed the character of the landscape. Perhaps the worst plague that man has set upon the *lomas* formations since the arrival of Europeans was the introduction of herbivores such as goats (Fig. 2F), which are very destructive to the native communities.

El Niño Events

In our search for the forces that act on the coastal regions, we identified short-term climatic fluctuations of El Niño events (5- to 50-year cycles) as important seasonal influences on the coastal region. The physics behind the El Niño–Southern Oscillation (ENSO) phenomenon is complex and represents a worldwide weather perturbation. El Niño conditions prevail when the normally cold waters of the coast of western South America are displaced by a warmer, western Pacific surface and subsurface body of water that stimulates brief periods of heavy rainfall (Fig. 2C) and relatively high temperatures. This influx of available moisture has profound effects within the *lomas* formations (Fig. 2D) and has undoubtedly helped shape their composition and structure. Primarily, this moisture stimulates massive germination of seeds, leading to large blooming events that replenish seed banks for annual and perennial plants. These events also provide opportunities for seed dispersal and establishment, which would expand distributions under favorable conditions (Fig. 2G). The impact of El Niños on these communities is obvious (Dillon and Rundel 1990), and one can only wonder what the coastal vegetation would resemble in the absence of these conditions. Potentially, levels of floristic diversity would be much lower and migration and establishment more difficult. In the western Pacific, the reverse effects of recurrent droughts and rainfall variability have been implicated in the evolution of vegetation patterns in Australia (Nicholls 1991).

El Niño events have been recorded in both historical (Quinn and Neal 1987) and Holocene periods (DeVries 1987; Fontugne et al. 1999; Magilligan and Goldstein 2001; Rodbell et al. 1999; Sandweiss et al. 1996, 1999, 2001). Longer-term records of El Niño events are more difficult to detect and interpret (Moseley 1987). Recently, Hughen et al. (1999) detected variability in growth patterns in fossil coral which they interpreted as representing El Niño-like conditions that may have existed for at least 124,000 years. Our studies of modern vegetation do not allow for estimations of the onset of El Niño conditions, but regardless of their age, they have undoubtedly played an important role in shaping the present coastal communities.

Glacial Cycles and Sea Level Changes

Longer-term climatic change associated with glacial cycles (13,000- to 200,000-year cycles) predates the arrival of man and the first El Niño and would have been active throughout the Pleistocene (±1.8 million years ago). It is estimated that there have been at least 20 glacial events during the Pleistocene, each with cycles of approximately 200,000 years. The formation of glaciers on mountains and poles has caused sea levels to fluctuate dramatically (Matthews 1990). Estimates of sea level fluctuation range between 400 and 750 feet (120–230 m), and this lowering would have significantly changed the position of the seashore in relation to that of today. This drop would have exposed a considerable area of the continental shelf and displaced *lomas* plant communities, especially between 5°S to 15°S latitude (Fig. 4). This would have resulted in species shifting their ranges in relation to the near-ocean environments, adapting to changing conditions in situ, or undergoing range reductions and extinction. Glacial cycles would also have had a profound influence on the flora and fauna of the coastal deserts by providing geographic isolation at certain times, and at other times, opportunities for merging species, thereby allowing for gene exchange. The last glacial cycle ended ca. 13,000 years ago, and postglacial vegetation patterns are comparable to those we find today (Dillon et al. 1995).

Nolana Studies

Within the *lomas* formations, the genus *Nolana* (Solanaceae-Nolaneae) stands out as one of the most wide-ranging and conspicuous elements of the flora (Tago-Nakazawa and Dillon 1999). *Nolana* is a genus of ca. 85 species that is largely confined to coastal Andean South America from central Chile to northern Peru, with one species endemic to the Galápagos Islands. It is the only genus to be encountered in nearly all *lomas* formations. *Nolana* species are often important members of their respective communities and dominate in the numbers of individuals present. Their showy flowers are beautiful, and species display various types of habits—annuals, perennials, or shrubs—and variable corolla sizes and shapes (Fig. 2H). Ecologically, *Nolana* species prefer arid and semi-arid habitats, with their greatest concentration in near-ocean habitats within a few kilometers of the shoreline (Fig. 2G). The establishment of a phylogeny for *Nolana* has provided a framework for testing hypotheses of isolation events in desert communities. The species distribution pattern in *Nolana* is similar to that in the overall flora and displays three distinctive units: northern Peru, southern Peru, and northern Chile. Only four species have distributions that span the 18°–20°S gap. The presence of two major groups (clades) in the genus *Nolana,* one Peruvian and the other Chilean, points to long-term isolation of the genus above and below 18°S latitude.

Reliable data on speciation rates for desert plants are largely lacking. However, the development of endemic genera and species, and the morphological and physiological adaptations they manifest, support the hypothesis of long-term aridity along the coast of Peru, at least from 12°S to 28°S latitude (Rundel and Dillon 1998). The timing of vicariant events (separation) can be estimated with molecular divergence data to establish a molecular clock (Tago 1999). For the genes investigated, all estimates for the first appearance of *Nolana* are late Tertiary (Miocene, 10.6–11.6 mya). These data also suggest that *N. galapagensis* potentially reached the Galápagos Islands sometime between 4 and 8 mya (late Miocene to early Pliocene). Because of character evolution in the mainland members of *Nolana,* it appears that *N. galapagensis* was pre-adapted to arid habitats prior to its dispersal to the island chain (Tago-Nakazawa and Dillon 1999). The geo-

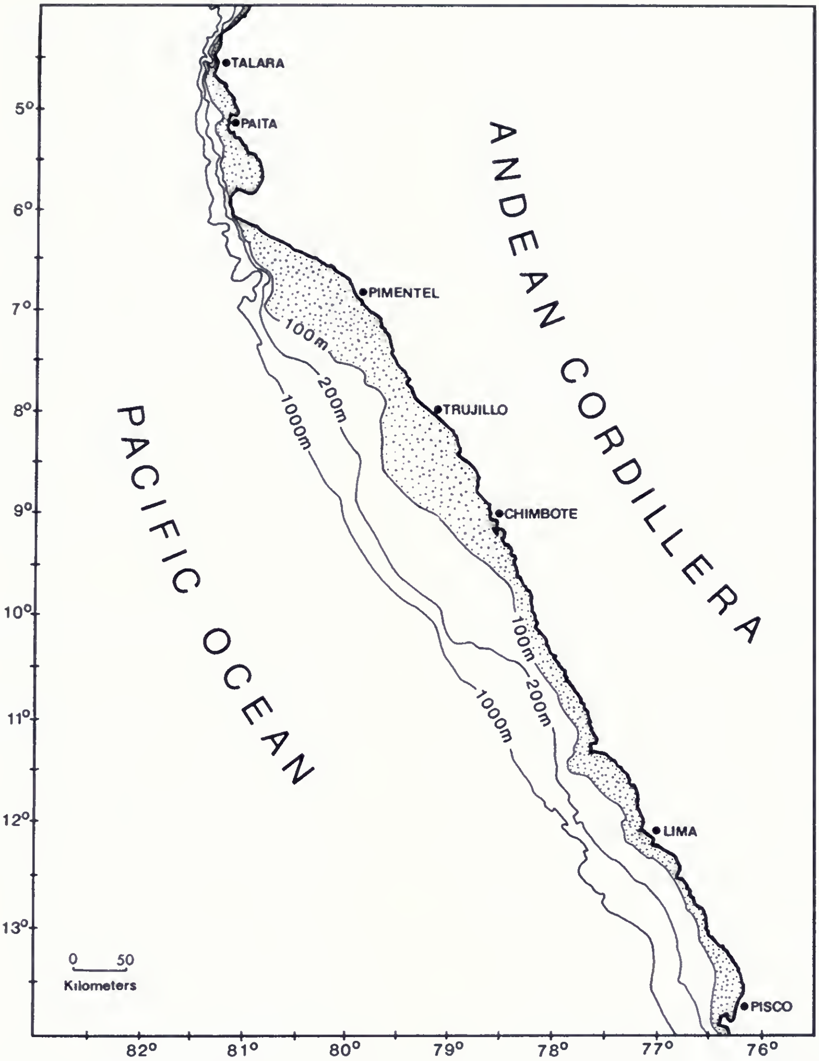

Figure 4. Bathometric diagram illustrating the continental shelf of Peru between 5°S and 14°S latitude. Stippled area indicates the land exposed should there be a 100-meter drop in sea level. Between 14°S latitude (Pisco, Peru) and 28°S latitude (northern Chile), the continental margin is very narrow.

graphic origin of this remote island endemic remains a mystery, but comparative morphology points to Chilean ancestors (Dillon, unpubl.).

Recent archeological findings from the northern Atacama Desert have recorded *Nolana* fruits (technically mericarps containing seeds) in rodent middens dating to 35,000 years B.P. (Betancourt et al. 2000). These mericarps are comparable to those we find in this desert locality today. Therefore, the divergence data from molecular studies and the presence of *Nolana* in desert habitats for no less than 35,000 years suggest that 10,000 years ago, the overall character of the coastal flora was similar to that found today. The frequency of strong El Niños and demonstrated sea level changes suggest that these phenomena have played a role in stimulating evolution in the plants of the *lomas* formations.

Conclusions

The vegetation of coastal Peru is largely restricted to the *lomas* formations, a series of isolated, fog-dependent plant and animal communities that are diverse and highly endemic. Individual *lomas* localities have unique species compositions and display disharmonic patterns found in "true" insular communities. While the aridity along the Peruvian coast is essentially constant, with negligible rainfall, the topography and geologic history combine to divide coastal Peru into a northern unit, 7°55′S to 12°S latitude, and a southern unit, from 12°S to 18°S latitude.

Given available paleoclimatic data and divergence times suggested by molecular clock calculations on gene sequences, it appears that *Nolana* occupied coastal desert environments in both Peru and Chile prior to the Pleistocene glacial events. Further investigations will be necessary to test hypotheses of the age for the desert, but our preliminary studies point to western South America as an arid region of great antiquity well over 35,000 years ago. It appears that the flora of the *lomas* formations have been shaped by the effects of short- and long-term climatic changes and by the influence of man and introduced animals. Our data suggest stabilized aridity for coastal Peru since before the arrival of its first inhabitants (±10,000 years ago), but with dynamic periods with much greater available moisture (Sandweiss et al. 2001). Early man would have found an environment with more trees and much denser vegetation, which could have provided valuable resources in the inhospitable coastal desert.

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Literature Cited

Alpers, C. N., and G. H. Brimhall. 1988. Middle Miocene climatic change in the Atacama Desert, northern Chile: Evidence from supergene mineralization at La Escondida. Geological Society of America Bulletin, **100:** 1640–1656.

Betancourt, J. L., C. Latorre, J. A. Rech, J. Quade, and K. A. Rylander. 2000. A 22,000-year record of monsoonal precipitation from northern Chile's Atacama Desert. Science, **289:** 1542–1546.

DeVries, T. J. 1987. A review of geological evidence for ancient El Niño activity in Peru. Journal of Geophysical Research, **92**(C13): 14471–14479.

Dillon, M. O. 1997. *Lomas* Formations—Peru, pp. 519–527. *In* Davis, S. D., V. H. Heywood, O. Herrera-McBryde, J. Villa-Lobos, and A. C. Hamilton, eds., Centres of Plant Diversity: A Guide and Strategy for their Conservation. World Wide Fund for Nature, Information Press, Oxford, United Kingdom.

Dillon, M. O., and P. W. Rundel. 1990. The botanical response of the Atacama and Peruvian desert flora to the 1982–83 El Niño event, pp. 487–504. *In* Glynn, P. W., ed., Global Ecological Consequences of the 1982–83 El Niño–Southern Oscillation. Elsevier, New York.

Dillon, M. O., A. Sagástegui A., I. Sánchez V., S. Llatas Q., and N. C. Hensold. 1995. Floristic inventory and biogeographic analysis of montane forests in northwestern Peru, pp. 251–270. *In* Churchill, S. P., H. Balslev, E. Forero, and J. L. Luteyn, eds., Biodiversity and Conservation of Neotropical Montane Forests. The New York Botanical Garden, Bronx, New York.

Duncan, T., and M. O. Dillon. 1991. Numerical analysis of the floristic relationships of the *lomas* of Peru and Chile, abstract. American Journal of Botany, **78:** 183.

Ferreyra, R. 1953. Comunidades des vegetales de algunas lomas costaneras del Perú. Estación Experimental Agricola "La Molina," Boletin, **53:** 1–88.

Fontuge, M., P. Usselmann, D. Lavallée, M. Julien, and C. Hatté. 1999. El Niño variability in the coastal desert of southern Peru during the Mid-Holocene. Quaternary Research, **52:** 171–179.

Hughen, K. A., D. P. Schrag, S. B. Jacobsen, and W. Hantoro. 1999. El Niño during the last interglacial period recorded by a fossil coral from Indonesia. Geophysical Research Letters, **26:** 3129.

Keefer, D. K., S. D. de France, M. E. Moseley, J. B. Richardson III, D. R. Satterlee, and A. Day-Lewis. 1998. Early maritime economy and El Niño events at Quebrada Tacahuay, Peru. Science, **281:** 1833–1835.

Lanning, E. P. 1965. Early man in Peru. Scientific American, **213:** 68–76.

Magilligan, F. J., and P. S. Goldstein. 2001. El Niño floods and culture change: A late Holocene flood history for the Rio Moquegua, southern Peru. Geology, **29:** 431–434.

Matthews, R. K. 1990. Quaternary sea-level change, pp. 88–103. *In* Sea-Level Change. National Academy Press, Washington, D.C.

Moseley, M. E. 1987. Punctuated equilibrium: Searching the ancient record for El Niño. Quarterly Review of Archaeology, **8:** 7–10.

Nicholls, N. 1991. The El Niño/Southern Oscillation and Australian vegetation. Vegetatio, **91:** 23–36.

Quinn, W. H., and V. T. Neal. 1987. El Niño occurrences over the past four and a half centuries. Journal of Geophysical Research, **92**(C13): 14449–14461.

Rodbell, D. T., G. O. Seltzer, D. M. Anderson, M.

B. Abbott, D. B. Enfield, and J. H. Newman. 1999. A ~15,000-year record of El Niño-driven alluviation in southwestern Ecuador. Science, **283:** 516–520.

Rundel, P. W., and M. O. Dillon. 1998. Ecological patterns in the Bromeliaceae of the *lomas* formations of coastal Chile and Peru. Plant Systematics and Evolution, **212:** 261–278.

Rundel, P. W., M. O. Dillon, H. A. Mooney, S. L. Gulmon, and J. R. Ehleringer. 1991. The phytogeography and ecology of the coastal Atacama and Peruvian deserts. Aliso, **13**(1): 1–50.

Sagástegui-A., A., and S. Leiva G. 1993. Flora Invasora de Los Cultivos del Perú. Editorial Libertad, Trujillo. 539 pp.

Sandweiss, D. H., K. A. Maasch, and D. G. Anderson. 1999. Transitions in the Mid-Holocene. Science, **283:** 499–500.

Sandweiss, D. H., K. A. Maasch, R. L. Burger, J. B. Richardson III, H. B. Rollins, and A. Clement. 2001. Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru: Geology, **29:** 603–606.

Sandweiss, D. H., J. B. Richardson III, E. J. Reitz, H. B. Rollins, and K. A. Maasch. 1996. Geoarchaeological evidence from Peru for a 5000 years B.P. onset of El Niño. Science, **273:** 1531–1533.

Tago, M. 1999. The Evolution of *Nolana* L. (Solanaceae) at *lomas* in South America. Ph.D. diss., Tokyo Metropolitan University, Tokyo, Japan.

Tago-Nakazawa, M., and M. O. Dillon. 1999. Biogeografía y evolución en el clado *Nolana* (Solaneae-Solanaceae). Arnaldoa, **6**(2): 81–116.

2

Response of a Land Snail Species (*Bostryx conspersus*) in the Peruvian Central Coast *Lomas* Ecosystem to the 1982–1983 and 1997–1998 El Niño Events

Rina Ramírez, Saida Córdova, Katia Caro, and Janine Duárez

Land snails are conspicuous inhabitants of the *lomas* ecosystems, which are islands of vegetation in the Pacific coastal desert of South America. The mollusks are adapted to survive the extreme summer conditions of the *lomas,* when the highest temperatures and the lowest humidities are reached. *Bostryx conspersus* (Sowerby, 1833; Mollusca, Bulimulidae) is the most common species from the *lomas* of the Peruvian central coast. In a year without an El Niño event, individuals of *B. conspersus* aestivate during the dry season (December–April) buried in the ground, mainly next to perennial plants. During the wet season the snails become active again. We present our observations of changes in snails' seasonal activity during the 1982–1983 and 1997–1998 El Niño events, occurring within the *lomas* of Iguanil and Lachay (Lima, Peru), respectively. The activity of *B. conspersus* during the summer of those years was unusual. The snails behaved as if it were a wet season. They had successful recruitment that led to a remarkable population explosion, mainly due to the high humidity and increased shelter. However, the response of *B. conspersus* showed differences between the two El Niño events, reflecting dissimilarities between the starting time and duration of the sea-surface temperature anomalies and the concomitant weather variation in the *lomas* of the central coast of Peru. The response of *B. conspersus* to the seasonal changes during 1995 and the cold year of 1996 are contrasted with those of the El Niño years.

Introduction

The coast of Peru is a desert. The terrestrial biodiversity, mollusks in particular, is concentrated mainly in the *lomas.* The desert landscape changes drastically during El Niño events, the oceanographic component of El Niño–Southern Oscillation (ENSO), which has affected the Pacific coast of South America since 5800 B.P. (Sandweiss et al. 1999). The *lomas* are spectacular ecosystems, islands of vegetation that endure the harsh conditions of dry summers and enjoy the humidity of the advective fogs coming from the ocean during the winter. The resident fauna of the *lomas* is also adapted to its seasonality (Aguilar 1954, 1985). Similarly, the biota must be adapted to climatic changes in the mid- and long term produced by recurrent El Niño events or the species would have become extinct. However, almost nothing is known about the responses of terrestrial species to El Niño events, compared to what is known about the marine biota (Arntz et al. 1985; Arntz and Fahrbach 1996; Vegas 1985). Among the fauna, land snails are conspicuous inhabitants of the *lomas,* and because of their low vagility, they are good animals in which to study responses to El Niño events. Following

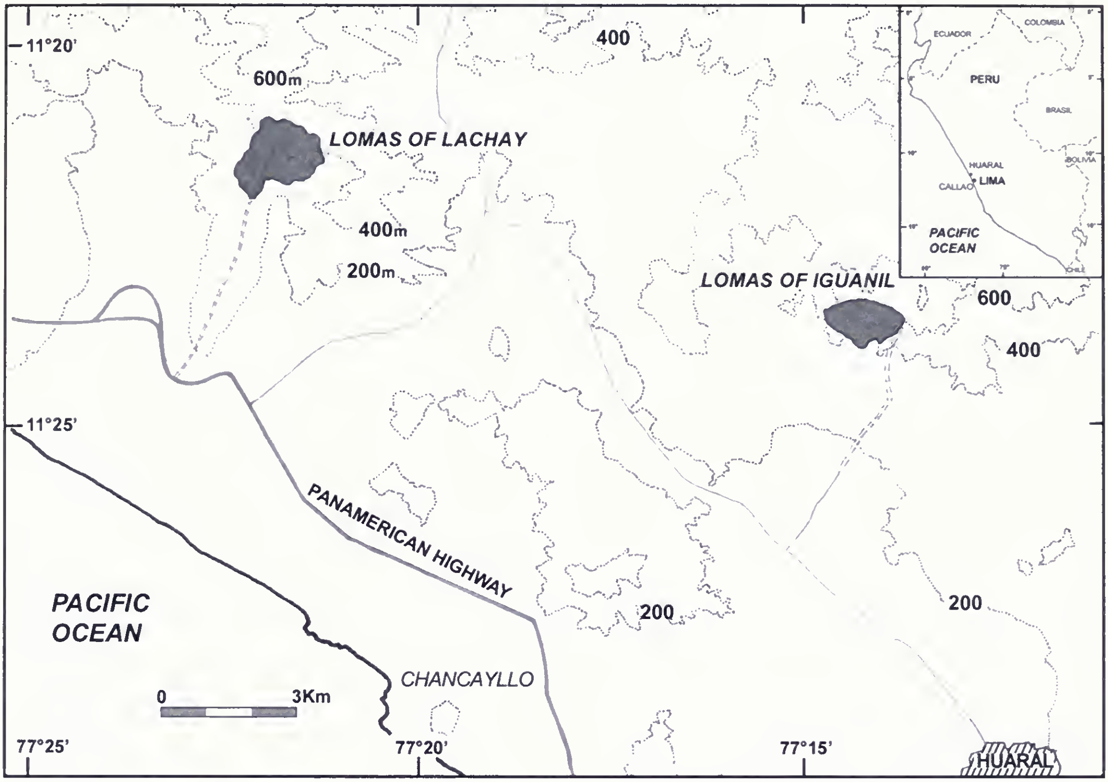

Figure 1. Map showing location of the study sites, Lachay and Iguanil, Peru.

an El Niño event (a phase with warm tropical water), there is a phase with cold tropical water called La Niña (Sandweiss et al. 1999), producing changes in the *lomas* weather as well. Our study deals with the response of *Bostryx conspersus* (Sowerby, 1833) to the last two major El Niño events (1982–1983 and 1997–1998) and the 1996 La Niña event in the *lomas* of the central coastal desert of Peru.

Materials and Methods

Study Site

Location. The two study sites are located in the Department of Lima, Peru (Fig. 1). The *lomas* of Lachay (11°19′S, 77°22′W), a national reserve, are 105 km north of Lima City and 7 km from the seashore. The altitude is between 150 and 750 m. The *lomas* of Iguanil (11°23′S, 77°14′W) are located southeast of Lachay and 103 km from Lima, 15 km from the seashore. The altitude is between 250 and 750 m.

Climate. The climate of the *lomas* is seasonal, characterized by a dry season (December–April) and a wet one, also called the "*lomas* season" (late July–September). The other months are transitional between seasons. Usually the highest temperatures (monthly mean: 20°C) and the lowest humidities (79%–82%) are reached during summer, contrary to what happens during the wet season, when the mean monthly air temperature is 15°C, with very high air humidity (Ordóñez and Faustino 1983; Saito 1976; Torres 1985). The El Niño events change this seasonal picture because of an increase in precipitation as drizzle or summer precipitation (Pinche 1994; Torres 1985).

During an El Niño event, the sea-surface temperature increases abnormally above the mean (Fig. 2). In the continental area, air temperatures in the *lomas* also change, showing the same tendency (Fig. 3). The same tendency was also noticed in Lima City (Obregón et al. 1985). Sea-surface temperature data corresponded to mean monthly values from Puerto Chicama (07°42′S, 79°27′W).

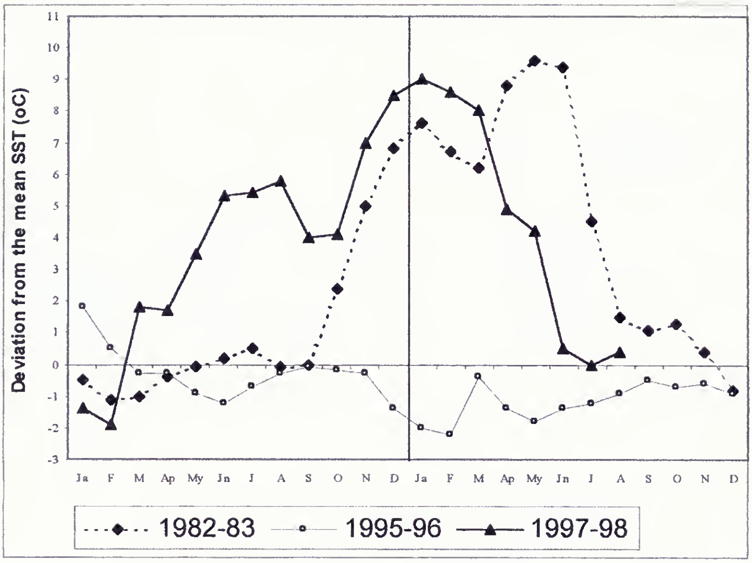

Figure 2. Sea-surface temperature anomalies at the Puerto Chicama station, Peru (07°42′S, 79°27′W). The characterization of years follows Aguilar (1990): El Niño events: >2.7 (extraordinary), 1.7–2.7 (strong), 0.8–1.6 (moderate), 0.5–0.7 (weak). A normal year is −0.6 to 0.4. La Niña events: −0.9 (cold year), −1.8 (very cold year).

Lomas of Iguanil During 1982–1983. The micrometeorologic data were recorded by CIZA (Arid Zones Research Center, Agrarian University, La Molina, Peru). Observations were taken during 10 hours of 1 day a month, at altitudes of 300 and 500 m. We used the mean values of the day for air temperature, relative humidity, and soil humidity. Precipitation values are from Torres (1985) (Table 1). The climatogram is shown in Figure 4.

Lomas of Lachay During 1995–1998. The data were acquired from SENAMHI (Servicio Nacional de Meteorología e Hidrografía del Perú). The data for both air temperature and relative humidity are mean monthly values; pre-

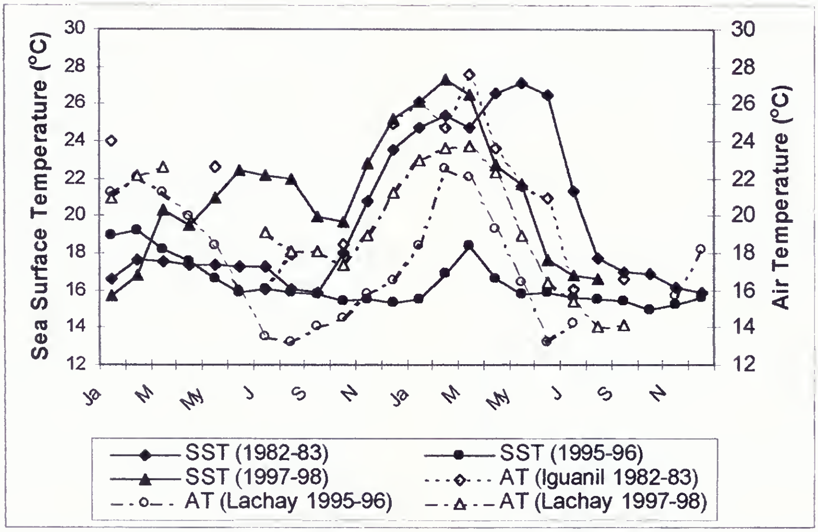

Figure 3. Comparison of sea-surface temperatures at the Puerto Chicama station and air temperatures at two *lomas* along the central coast of Peru.

TABLE 1. The *lomas* of Iguanil: Meteorologic and biologic data (1982–1983).

Month, year	Air temp. (°C)	Relative humidity (%)	Soil humidity (%)	Precipitation (mm)*	Ground cover (%)*	*B. conspersus* (no. snails/ 9400 m²)
Jan. '82 (Ja2)	23.99	77.49	1.18		0.81	
Mar. '82 (M2)			1.05			
May '82 (My2)	22.6	72.15	0.85		2.55	0
July '82 (J2)	16.05	85.08	0.82		5.025	15
Aug. '82 (A2)	17.89	86.62	5.09		3.3	23
Sept. '82 (S2)					38	
Oct. '82 (O2)	18.42	80.12	3.27		38.65	43
Nov. '82 (N2)					12.5	
Dec. '82 (D2)	24.88	73.76	1.895		30	7
Jan. '83 (Ja3)	26.13	76.34	2.49	7	44.15	0
Feb. '83 (F3)	24.72	80.4	2.815	8	64.3	0
Mar. '83 (M3)	27.57	65.07	0.915		45.8	6
Apr. '83 (Ap3)	23.59	93.44	6.83	6		94
May '83 (My3)	21.59	94.14	3.2	5	47.9	24
June '83 (Jn3)	20.93	96.06		9	75.65	
July '83 (J3)	16.09	93.65	8.5	5	94	118
Sept. '83 (S3)	16.66	97.17	6		54.5	

* After Torres (1985).

cipitation is the cumulative monthly value (Table 2). The climatogram is shown in Figure 5.

Vegetation. The *lomas* vegetation consists of herbaceous species that are green mainly during the wet season, and also perennial species (shrubs and trees) that adapt to the seasonality of the *lomas* (Dillon and Rundel 1989; Ferreyra 1993; Ono 1986). In general, changes in climate conditions during the year modify the landscape

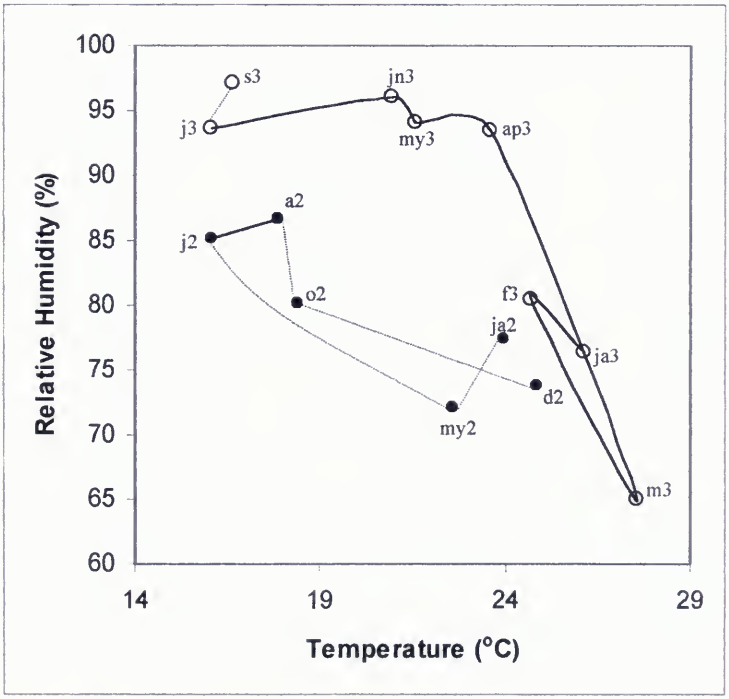

Figure 4. Climatogram of the *lomas* of Iguanil, Peru, 1982–1983.

TABLE 2. The *lomas* of Lachay: Meteorologic and biologic data (1995–1998).

Month, year	Air temp. (°C)	Relative humidity (%)	Precipitation (mm)	RGC* (%)	*B. conspersus* (no. snails/400 m^2)
Jan. '95 (Ja5)	21.2	89	3.5		
Feb. '95 (F5)	22.1	85	0.5		
Mar. '95 (M5)	21.2	84	1.4		
Apr. '95 (Ap5)	19.9	86			
May '95 (My5)	18.4	86	0.7		
June '95 (Jn5)	16	92	2		
July '95 (J5)	13.5	97	19.9	72	0
Aug. '95 (A5)	13.2	98	4.7	1271	3
Sept. '95 (S5)	14	97	17.2	1492	69
Oct. '95 (O5)	14.5	96	10.5	456	85
Nov. '95 (N5)	15.8	92	1.6	681	54
Dec. '95 (D5)	16.5	89	1.4	0	207
Jan. '96 (Ja6)	18.4	88	1.1	0	21
Feb. '96 (F6)	22.5	82		0	20
Mar. '96 (M6)	22.1	79		0	7
Apr. '96 (Ap6)	19.3	81	0.4	0	7
May '96 (My6)	16.4	88		0	31
June '96 (Jn6)	13.2	98	0	278	43
July '96 (J6)	14.2	97	0		
Aug. '96 (A6)				368	89
Sept. '96 (S6)				147	60
Oct. '96 (O6)				39	12
Nov. '96 (N6)	15.7	91	0	2	25
Dec. '96 (D6)	18.2	89	0	0	10
Jan. '97 (Ja7)	21	95	0		
Feb. '97 (F7)	22.2	93	0		
Mar. '97 (M7)	22.6	97	0	0	0
May '97 (My7)					0
July '97 (J7)	19.1	96	10.7	0	3
Aug. '97 (A7)	18.1	95	31.7	211	8
Sept. '97 (S7)	18.1	93	40.4	1345	6
Oct. '97 (O7)	17.4	92	28.4	927	13
Nov. '97 (N7)	18.9	93	20.4	373	2
Dec. '97 (D7)	21.2	94	65.2	237	5
Jan. '98 (Ja8)	23	96	103.1	476	220
Feb. '98 (F8)	23.6	95	47.5	980	552
Mar. '98 (M8)	23.7	91	6	724	637
Apr. '98 (Ap8)	22.3	88	2.5	321	146
May '98 (My8)	18.9	93	16.5	325	897
June '98 (Jn8)	16.4	98	34.5	529	1587
July '98 (J8)	15.4	97	16.4	907	1473
Aug. '98 (A8)	14	99	46.4	763	5448
Sept. '98 (S8)	14.1	99	28.2	806	9369

* Reiterated ground cover.

from a brown color (almost zero ground cover) during summer to a vivid green color during winter, when the annual species provide a large amount of ground cover. However, during El Niño events, the timing of these changes is very different, as was observed during the 1982–1983 El Niño event in Iguanil (Torres 1985) and in 1997–1998 in Lachay (Arana et al. 1998). Ground cover data for Iguanil are from Torres (1985). We used the mean values for each month (Table 1). For Lachay, we used the "reiterated ground cover" figure obtained by the botanical team from the Museum of Natural History of the University of San Marcos (Table 2).

Mollusks. *Bostryx conspersus* (Sowerby, 1833; Gastropoda, Bulimulidae) has a globose and rather thin shell of about 15 mm height (Fig. 6c). It has been recorded in the *lomas* of central and southern Peru (Departments of Lima and Arequipa) (Aguilar and Arrarte 1974;

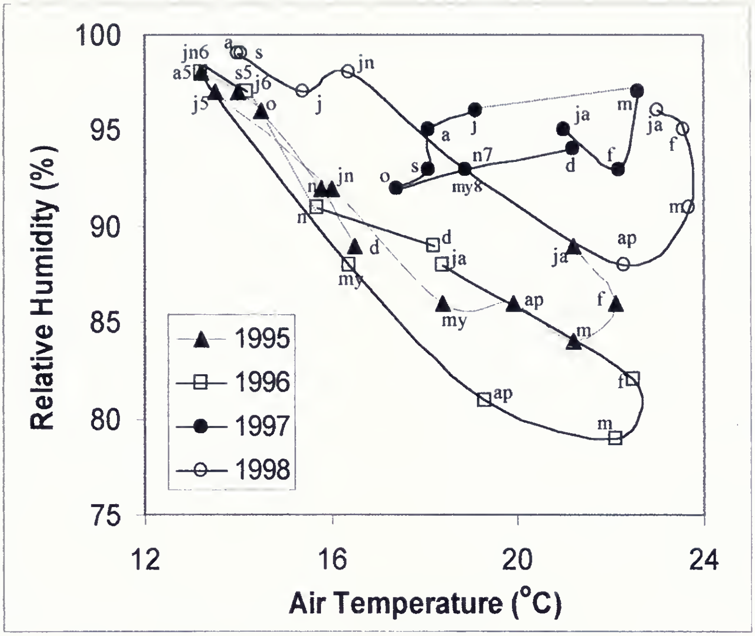

Figure 5. Climatogram of the *lomas* of Lachay, Peru, 1995–1998.

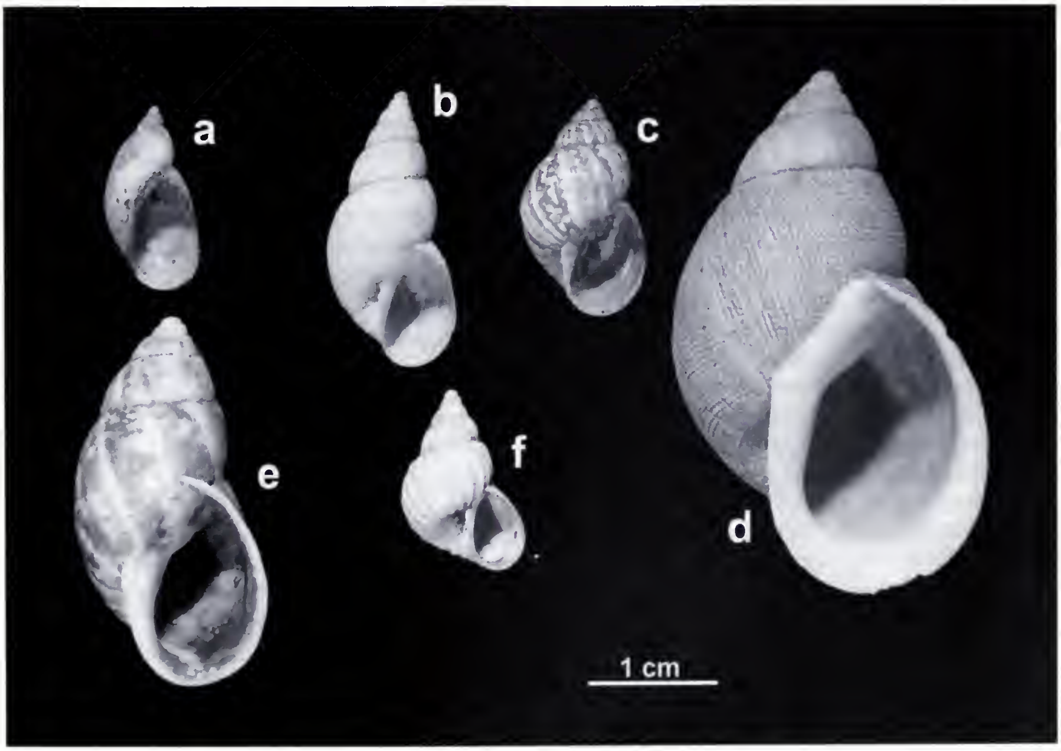

Figure 6. Some lands snails from Lachay: **a,** *Succinea peruviana;* **b,** *Bostryx modestus;* **c,** *Bostryx conspersus;* **d,** *Scutalus proteus;* **e,** *Scutalus versicolor;* **f,** *Bostryx scalariformis.* (Photograph by B. Collantes.)

Weyrauch 1967). Individuals of *B. conspersus* aestivate during the dry season buried in the ground, mainly next to perennial plants. They are also found buried adjacent to rocks, or in small interstices between them. During the wet season the snails become active again (Pulido and Ramírez 1982; Ramírez 1988).

B. conspersus shares the *lomas* with other land snail species. For example, in Lachay the following native species are also present: *Bostryx aguilari* Weyrauch, 1967; *B. modestus* (Broderip, 1832) (Fig. 6b); *B. scalariformis* (Broderip, 1832) (Fig. 6f); *Scutalus proteus* (Broderip, 1832) (Fig. 6d); *Scutalus versicolor* (Broderip, 1832) (Fig. 6e); *Succinea peruviana* Philippi, 1867 (Fig. 6a); and the two minutes *Pupoides paredesi* (d'Orbigny, 1835) and *Gastrocopta pazi* (Hidalgo, 1869), as well as the introduced *Helix aspersa* (Müller, 1774).

Monitoring

***Lomas* of Iguanil.** The study area in the *lomas* of Iguanil was the Quebrada El Granado. The quantitative survey was carried out 1 day a month in a transect of 20 × 470 m (= 9,400 m^2) between 420 and 600 m above sea level. The transect is located in a hilly area along the center of the ravine, with perennial vegetation (mainly shrubs, e.g., *Trixis cacalioides, Ophryosporus pubescens, Cestrum auriculatus, Dicliptera tomentosa, Heliotropium* spp.). There is also annual herbaceous vegetation (e.g., *Nicotiana paniculata, Chenopodium petiolare, Oxalis* sp., *Sicyos baderoa*). The survey was carried out from May 1982 to July 1983 (except June 1983). The search for unburied snails was conducted by direct observation. R. Ramírez carried out this part of the work as a member of a team of the CIZA/UNA–La Molina (Lima, Peru), which conducted botanical, faunal, and anthropological research in several *lomas* of the central coast of Peru during the 1970s and 1980s.

***Lomas* of Lachay.** The Museum of Natural History of the University of San Marcos, Lima, Peru, has been engaged in monitoring vegetation and mollusks to track El Niño events in the *lomas* ecosystems as part of the RIBEN study (Red de Impacto Biológico de los Eventos El Niño, CONCYTEC) from May 1995 to the present.

For a quantitative survey, we selected an area dominated by shrubs (e.g., *Ophryosporus peruvianus, Senecio* spp., *Trixis cacalioides, Croton* spp.), including annual herbaceous vegetation (e.g., *Loasa urens, Nicotiana paniculata, Urocarpidium peruvianum, Nolana humifusa*). Monitoring of the land snails at the two *lomas* was carried out as independent projects. Although we tried to maintain the same area in Lachay for quantitative sampling as in Iguanil, it did not work as well because of the greater abundance of *B. conspersus*. We delimited four plots of 10 × 10 m (= 400 m^2), 50 m apart, along a transect between 470 and 550 m in altitude. We counted the unburied snails observed in 1 day per month, except during 1998, when we needed an extra day because of the high number of individuals and the exuberant herbaceous vegetation. The data we present here are from July 1995 to September 1998. No survey was conducted in July 1996 or in January, February, April, or June of 1997.

Principal Component Analysis

We used principal component analysis (PCA) to ascertain whether changes in monthly density of *B. conspersus* along with changes in air temperature, relative humidity, or ground cover could help discriminate El Niño months from non-El Niño months. We did not use the precipitation data, which were incomplete. Microsoft Excel was used for data management and the analyses were performed using SPSS (Statistical Package for the Social Sciences, V05) software.

Results

Iguanil (1982–1983)

The monthly variation in number of unburied individuals of *Bostryx conspersus* in the *lomas* of Iguanil did not show the same trend from one year to the next. In 1982 the snails were active during part of the winter and spring, whereas in 1983 the activity period started earlier, at the end of the summer. The highest number of snails recorded in 1983 was recorded earlier, in July, and was almost threefold (118 individuals in 9,400 m^2) the number recorded in

1982 (October, 43 individuals) (Table 1, Fig. 7a).

In relation to the differences among survey months, PCA of data on snails, ground cover, air temperature, and relative humidity generated four components to explain the total variance. The PC1 analysis explained 62.157% of the variance, with variation in number of snails having the greatest influence, followed by variation in the relative humidity. In the PC2 analysis (28.492%) ground cover was the principal factor, followed rather distantly by air temperature (Table 3). In the scatter diagram of PC1 × PC2, three groups of months are formed, with the months of the 1982–1983 El Niño episode in two of them (December 1982–March 1983, and May–July 1983) (Fig. 8).

Lachay (1995–1998)

During the almost 4 years of survey of *B. conspersus* in the *lomas* of Lachay, the higher number of active snails (unburied) per observation period decreased from 1995 through 1997, but in 1998 exceeded the highest counts of previous years. The lowest numbers of snails occurred during the summer of 1996 and the summer of 1997, corresponding to the aestivation period (Table 2, Fig. 7b).

In relation to the differences among the survey months, PCA generated four components to explain the total variance, of which the first two accounted for 71.412% of the variance. In PC1 (52.046%), variation in relative humidity had the greatest influence, followed by variation in air temperature, while in PC2 (19.366%), the number of snails and the ground cover were the variables with greatest influence (Table 4). In the scatter diagram of the first two components, five groups of months were formed. Those of the 1997–1998 El Niño segregated into two groups (March–July–August 1997, and September–December 1997–January–April 1998); the following months (post-El Niño) also formed a separate group (June–September 1998). The two other groups were formed by (1) August–November 1995 and (2) December 1995–January–May 1996 and November–December 1996 (Fig. 9).

Discussion

Bostryx conspersus has seasonal behavior, showing a clear response to the seasonal climate of the *lomas* ecosystem (Pulido and Ramírez 1982; Ramírez 1988). The intensity of change in the climatic regimen can be detected from the variation in monthly number of unburied snails, as described here. El Niño events change the seasonality of the *lomas,* mainly because of summer rains (Oka and Ogawa 1984; Pinche 1994).

Climatologically, no one year was similar to any other during the study (Figs. 4 and 5), nor were the monthly density variations in active land snails similar (Fig. 7). Analysis of the sea-surface temperature anomalies at Puerto Chicama during the periods of our studies (1982–1983, 1995–1998) (Fig. 2; Quispe 1993) shows that in this respect too, there were not two equal years (Rasmusson and Arkin 1985). This demonstrates the direct influence of the ocean on the climate of the *lomas* as well as other continental areas (Obregón et al. 1985). Likewise, we cannot say that during the period of survey in the *lomas* of Lachay there was a "normal" year for the *lomas.* On the contrary, we had the El Niño years (1997–1998), an unusually cold year (La Niña, 1996), and a mixed warm and mildly cold year (1995).

Using the data of *B. conspersus* along with those of air temperature, relative humidity, and ground cover, then performing a principal component analysis, we arrived at assemblages of El Niño months that were arranged in a different way from those of non-El Niño ones. At the same time, months during El Niño events were segregated into two groups; we call them the first phase and the second phase of El Niño (Figs. 8 and 9). Checking the anomalies of sea-surface temperature, it is also possible to see that the two El Niño events were indeed different.

The 1982–1983 and 1997–1998 El Niño episodes are considered to be extraordinary because the sea-surface temperature anomalies differed by more than 2.7 SD (Fig. 2) (Aguilar 1990; Quinn 1993). At the same time, the El Niño events differed in starting point and in duration. For example, in the 1982–1983 El Niño event, warm water reached the central coast of Peru late in 1982—November in Callao (Gómez 1985)—and did not affect the wet season of the year very much. *B. conspersus* showed a typical seasonal behavior during that year. The

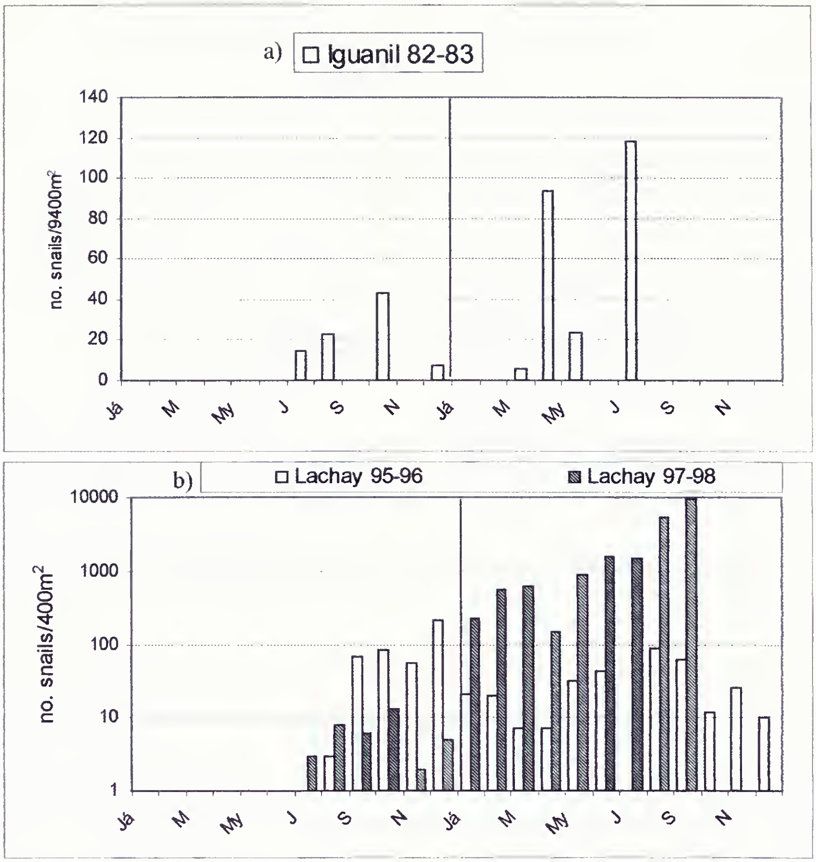

Figure 7. Monthly density of unburied individuals of *Bostryx conspersus* in two *lomas* on the central coast of Peru: **a,** Iguanil; **b,** Lachay.

second instance of warming of the sea-surface water occurred during the fall of 1983—April–July (Zuta et al. 1985)—which brought more precipitation to the *lomas,* marking an early beginning of the wet season in 1983 (Fig. 10). The usual brown landscape of the summer was replaced by a nice carpet of herbaceous vegetation (Torres 1985). The population of *B. conspersus* from the *lomas* of Iguanil also responded to the quasi-*lomas* season, the difference being that the air temperatures were higher than during the winter wet season (Fig. 4). The biological impact on the snails was positive; the snails awoke earlier from the aestivation period, and the recruitment was successful (Ramírez 1984). The population reached the levels of the previous wet season very early (Fig. 7). A possible reason for this could be the survival of

Table 3. Results of PCA for the *lomas* of Iguanil (1982–1983).

	Initial Eigenvalues				Component			
Component	Total	% of Variance	Cumulative %	Variables	1	2	3	4
1	2.486	62.157	62.157	Air temperature	−0.801	0.561	0.165	0.127
2	1.140	28.492	90.649	Relative humidity	0.872	−0.197	0.444	0.052
3	0.332	8.302	98.951	Ground cover	0.495	0.860	0.074	−0.099
4	0.042	1.049	100.000	*Bostryx conspersus*	0.916	0.214	−0.319	0.115

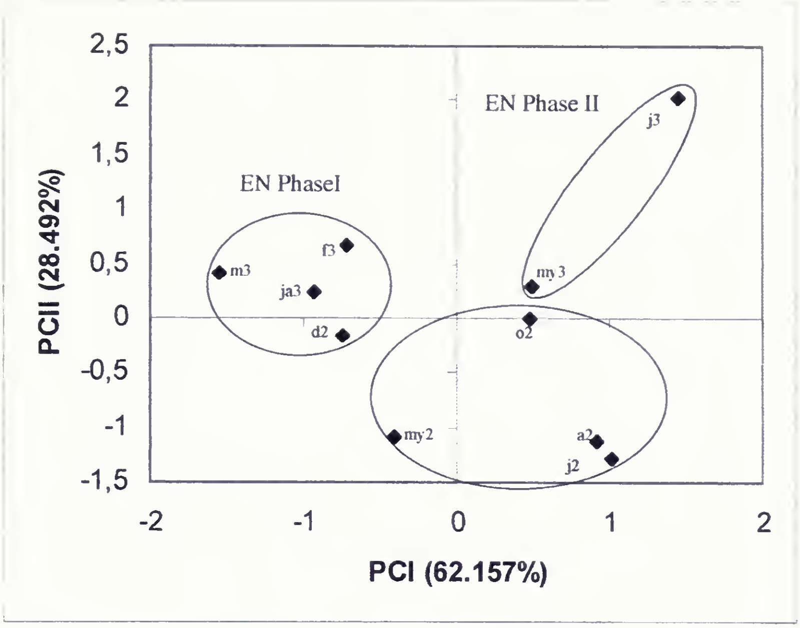

Figure 8. Plots of the first two principal components for the months May 1982 to July 1983 for the *lomas* of Iguanil.

more eggs and snails (especially just hatched and juveniles) than usual (Ramírez 1984) because of the high humidity (the main cause of death is desiccation [Pollard 1975]) and more available shelter (Lomincki in Pollard 1975) because of the high amount of annual vegetation.

The two instances of sea-surface warming during the 1997–1998 El Niño event occurred earlier than those of the 1982–1983 El Niño event. The first arrival of the warm water was early during the fall of 1997 (Fig. 2). The whole year was abnormally warm in the *lomas,* and during the winter the high relative humidity values characteristic of the "*lomas* season" were never reached; the contrary happened during the late spring, which had high relative humidity values, as shown in the climatogram for Lachay (Fig. 5). The characteristic herbaceous vegetation of the wet season was negatively affected. For example, *Isemene amancaes* had both a late beginning and a short development period during 1997 (Agüero and Suni 1999). The population of *B. conspersus* was also negatively impacted. Most of the snails stayed buried, and those that "woke up" were more exposed to desiccation. As a consequence, the recruitment was very poor (Fig. 11). The second occurrence of warming of the 1997–1998 El Niño event was at the beginning of the summer of 1998 (Fig. 2) and brought an unusual amount of water to the *lomas* (Fig. 12), extending the late wet season of 1997 into the summer of 1998. Here the impact of the El Niño event was positive for *B. conspersus,* which showed a

TABLE 4. Results of PCA for the *lomas* of Lachay (1995–1998).

	Initial Eigenvalues				Component			
Component	Total	% of Variance	Cumulative %	Variables	1	2	3	4
1	2.082	52.046	52.046	Air temperature	−0.707	0.218	0.622	0.255
2	0.775	19.366	71.412	Relative humidity	0.833	0.160	−0.076	0.524
3	0.704	17.602	89.014	Ground cover	0.698	0.578	0.288	−0.308
4	0.439	10.986	100.000	*Bostryx conspersus*	0.633	−0.606	0.478	−0.064

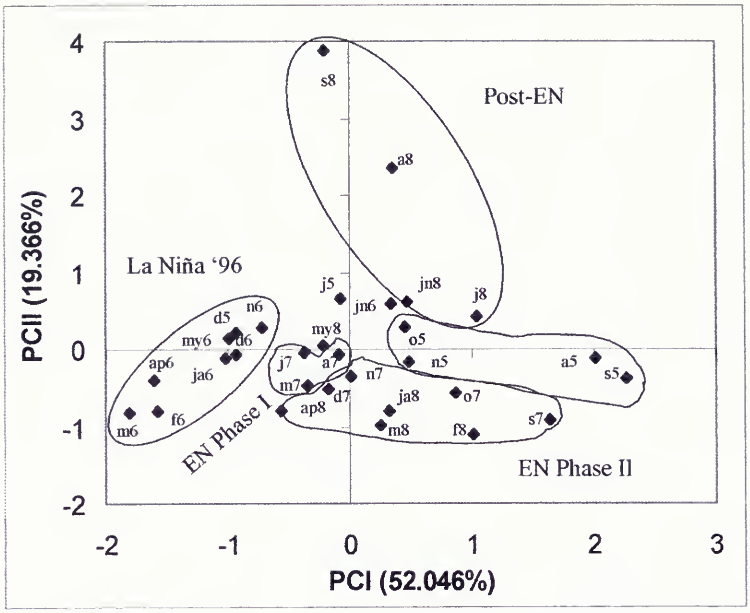

Figure 9. Plots of the first two principal components for the months July 1995 to September 1998 for the *lomas* of Lachay.

population explosion. The recruitment was very successful; and that, along with the high humidity and exuberant herbaceous vegetation (Arana et al. 1998, 1999), led to a high survival rate among the snails.

The cold year of 1996 (La Niña) had a relatively negative impact on *B. conspersus* compared with the maximum number of snails counted in the 1995 "wet season." The weather was colder and drier than during the other years (Figs. 5 and 12). The mortality rate of individuals of all size classes was high, and the recruitment was poor (Fig. 11; Ramírez et al. 1999). Affected in this way, the population experienced an El Niño the following year (1997), with a hot winter and without the characteristic high humidities (Fig. 5), depleting the population even more. Finally, the arrival of the second phase of the 1997–1998 El Niño event injected some life into *B. conspersus.* The range

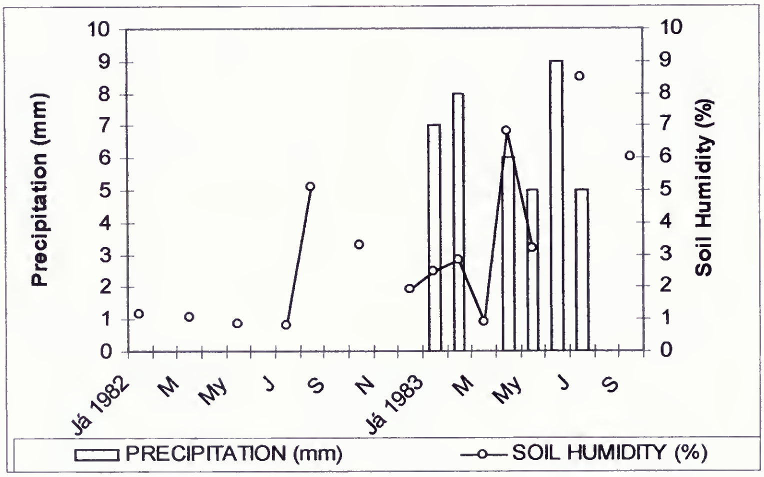

Figure 10. Precipitation and soil humidity in the *lomas* of Iguanil, 1982–1983 (measured 1 day per month).

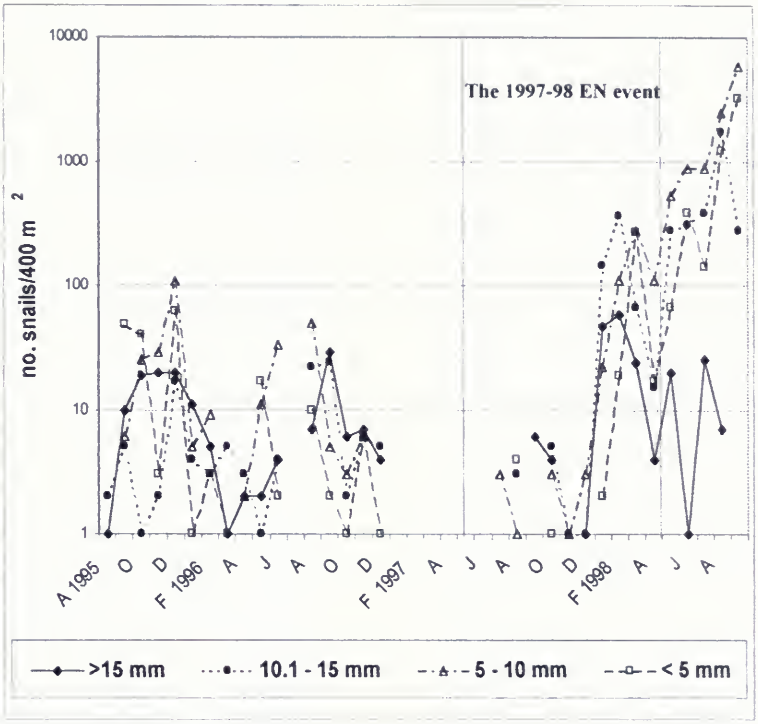

Figure 11. Structure of the population of *Bostryx conspersus* by size classes from August 1995 to September 1998 in the *lomas* of Lachay. The El Niño event occurred from May 1997 to April 1998. (After Ramírez et al. 1999.)

of the population expanded as far as the herbaceous vegetation did. The post-El Niño months following the 1997–1998 event coincided with the 1998 wet season, which resulted in an even higher density of active *B. conspersus*. This was probably also the case for 1995 (end of a weaker but much longer-lasting El Niño than the two episodes analyzed here). Precipitation and ground cover were greater than in 1996 (Table 2, Fig. 12), and *B. conspersus* reached higher densities than in 1996 and 1997 (Figs. 7b and 9).

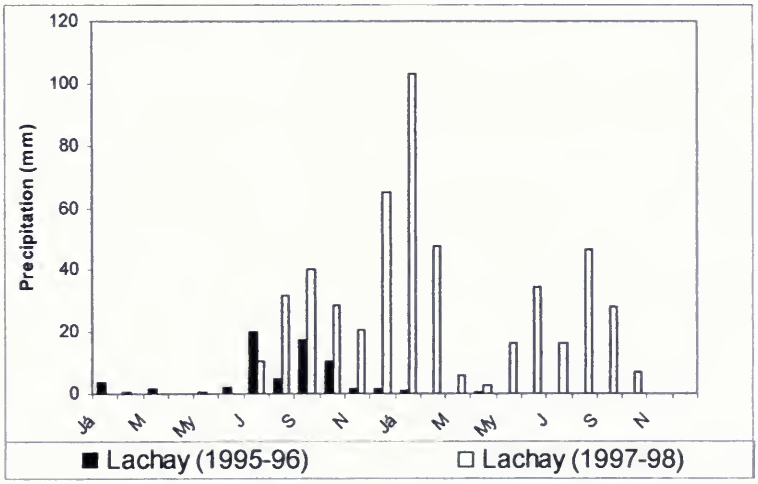

Figure 12. Precipitation in the *lomas* of Lachay, 1995–1998 (cumulative monthly values).

Thus, although the two El Niño episodes differed from each other, they were similar in that their second phase had a positive impact on the biota. The increase in humidity led to an increase in herbaceous vegetation, and both of these factors contributed to an increase in the population of *B. conspersus.* At the same time, predation on this population, mainly by rodents and birds, also increased (Ramírez et al. 1999).

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Literature Cited

AGÜERO, S., AND M. SUNI. 1999. Influencia del evento "El Niño 1997–98" en la fenología de *Iseme amancaes* (Amaryllidaceae, Liliopsidae). Revista Peruana de Biología, Volume Extraordinario, pp. 118–124.

AGUILAR, P. 1954. Estudio sobre las adaptaciones de los artrópodos a la vida de las lomas de los alrededores de Lima. Ph.D. diss., Universidad Nacional Mayor de San Marcos, Lima, Peru.

———. 1985. Fauna de las lomas costeras del Perú. Boletín de Lima (Perú), **41:** 17–28.

———. 1990. Sinopsis sobre los eventos del fenómeno "El Niño" en el Perú. Boletín de Lima, **70:** 69–84.

AGUILAR, P., AND J. ARRARTE. 1974. Moluscos de las lomas costeras del Perú. Anales Científicos, Universidad Nacional Agraria (Perú), **12**(3–4): 93–98.

ARANA, C., A. CANO, J. ROQUE, AND M. ARAKAKI. 1999. Patrones de respuesta poblacional de las herbáceas de "lomas" al evento "El Niño." VIII Reunión Científica, Instituto de Investigación de Ciencias Biológicas "Antonio Raimondi," 14–16 April, 1999; abstracts, p. 101.

ARANA, C., A. CANO, J. ROQUE, M. ARAKAKI, AND M. LA TORRE. 1998. Respuesta de la comunidad de herbáceas de las lomas de Lachay al evento "El Niño" 1997–98, p. 48. *In* Seminario Taller "El Niño" en América Latina, sus Impactos Biológicos y Sociales: Bases para un Monitoreo Regional. CONCYTEC–RIBEN. Lima, Perú, 9–13 November 1998.

ARNTZ, W., AND E. FAHRBACH. 1996. El Niño: Experimento climático de la naturaleza. Causas físicas y efectos biológicos. Fondo de Cultura Económica, Mexico, D.F., 312 pp.

ARNTZ, W., A. LANDA, AND J. TARAZONA, EDS. 1985. "El Niño": Su impacto en la fauna marina. Boletín del Instituto del Mar del Perú, Boletín Extraordinario, 222 pp.

DILLON, M., AND P. RUNDEL. 1989. The botanical response of the Atacama and Peruvian desert floras to the 1982–83 El Niño event. *In* Glynn, ed., Global Ecological Consequences of the 1982–83 El Niño–Southern Oscillation. Elsevier, New York.

FERREYRA, R. 1993. Registros de la vegetación en la costa peruana en relación con el fenómeno El Niño. Bulletin Institute Français Études Andines, **22**(1): 259–266.

GÓMEZ, D. 1985. Análisis de las anomalías de la presión y temperatura en la costa peruana como indicadores de la presencia del fenómeno "El Niño," pp. 241–261. *In* Vegas, M., ed., Ciencia, tecnología y agresión ambiental: El fenómeno "El Niño." CONCYTEC, Lima, Peru.

OBRÉGON, G., E. CISNEROS, AND A. DIA. 1985. El fenómeno "El Niño" 82–83 y la alteración térmica en Lima, pp. 263–278. *In* M. Vegas, ed., Ciencia, tecnología y agresión ambiental: El fenómeno El Niño. CONCYTEC, Lima, Peru.

OKA, S., AND H. OGAWA. 1984. The distribution of *lomas* vegetation and its climatic environments along the Pacific coast of Peru. Geographical Reports of Tokyo Metropolitan University, **19:** 113–125.

ONO, M. 1986. Definition, classification and taxonomic significance of the *lomas* vegetation, pp. 5–14. *In* Ono, M., ed., Taxonomic and Ecological Studies on the Lomas Vegetation in the Pacific Coast of Peru: Reports for Overseas Scientific Survey. Makino Herbarium, Tokyo Metropolitan University, Japan.

ORDOÑEZ, J., AND J. FAUSTINO. 1983. Evaluación del potencial hídrico en lomas costeras del Perú (lomas de Lachay–Iguanil). Zonas Aridas, **3:** 29–42.

PINCHE, C. 1994. Estudio de las condiciones climáticas y de la niebla en la costa norte de Lima. Boletín de Lima, **16**(91–96): 39–43.

POLLARD, E. 1975. Aspects of the ecology of *Helix pomatia* L. Journal of Animal Ecology, **44**(1): 305–329.

PULIDO, V., AND R. RAMÍREZ. 1982. Distribución y actividad estacional de los caracoles terrestres de las Lomas de Lachay. VII Congreso Nacional de Biología y II Simposium de Educación en Ciencias

Biológicas, Lima, Perú, 22–27 Noviembre. Bitácora Biológica (Libro de Resúmenes), **1**(1): 52.

Quinn, W. 1993. The large-scale ENSO event, the El Niño and other important regional features. Bulletin Institute Français Études Andines, **22**(1): 13–34.

Quispe, J. 1993. Variaciones de la temperatura superficial del mar en Puerto Chicama y del Indice de Oscilación del Sur: 1925–1992. Bulletin Institute Français Études Andines, **22**(1): 111–124.

Ramírez, R. 1984. Aspectos de la ecología de *Bostryx conspersus* (Sowerby, 1833) (Mollusca, Bulimulidae) en las lomas de Iguanil, Huaral-Lima. Informe de Prácticas Pre-Profesionales para optar el Título Profesional de Biólogo. Universidad Nacional Mayor de San Marcos, Lima, Peru.

———. 1988. Morfología y biología de *Bostryx conspersus* (Sowerby) (Mollusca, Bulimulidae) en las lomas costeras del Perú central. Revista Bras. Zool., **5**(4): 609–617.

Ramírez, R., K. Caro, S. Córdova, J. Duárez, A. Cano, C. Arana, and J. Roque. 1999. Respuesta de *Bostryx conspersus* y *Succinea peruviana* (Mollusca, Gastropoda) al evento "El Niño" 1997–98 en las lomas de Lachay (Lima, Peru). Revista Peruana de Biología, Volume Extraordinario, pp. 143–151.

Rasmusson, E., and P. Arkin. 1985. Interannual climate variability over South America and the Pacific associated with El Niño episodes, pp. 179–206. *In* Vegas, M., ed., Ciencia, tecnología y agresión ambiental: El fenómeno "El Niño." CONCYTEC, Lima, Peru.

Saito, C. 1976. Bases para el establecimiento y manejo de una unidad de conservación en las Lomas de Lachay, Perú. Ministerio de Agricultura, Dirección General Forestal y de Fauna, Dirección de Conservación, 205 pp.

Sandweiss, D. H., K. A. Maasch, and D. G. Anderson. 1999. Transitions in the Mid-Holocene. Science, **283:** 499–500.

Torres, J. 1985. Anomalías observadas en la vegetación y sus factores físicos determinantes en las lomas de la Costa Central, durante el verano (Enero–Abril) de 1983, pp. 625–642. *In* Vegas, M., ed., Ciencia, tecnología y agresión ambiental: El fenómeno "El Niño." CONCYTEC, Lima, Peru, 692 pp.

Vegas, M., ed. 1985. Ciencia, tecnología y agresión ambiental: El fenómeno El Niño. CONCYTEC, Lima, Peru, 692 pp.

Weyrauch, W. 1967. Descripciones y notas sobre gasterópodos terrestres de Venezuela, Colombia, Ecuador, Brasil y Perú. Acta Zool. Lilloana, **21:** 457–499.

Zuta, S., M. Farfan, and O. Moron. 1985. Fluctuaciones de la TSM y SSM durante el evento El Niño 1982–83, pp. 57–94. *In* Vegas, M., ed., Ciencia, tecnología y agresión ambiental: El fenómeno El Niño. CONCYTEC, Lima, Peru.

3

Debris-Flow Deposits and El Niño Impacts Along the Hyperarid Southern Peru Coast

Luc Ortlieb and Gabriel Vargas

The coastal regions of Ecuador, Peru, and Chile, which today experience the strongest meteorologic and oceanographic impacts of El Niño, are also the areas where paleoclimatologic research is likely to yield relevant information about former El Niño processes. The extreme aridity that characterizes the coast of southern Peru and northern Chile is favorable for the record of episodic rainfall events that induce floods and debris flows and the subsequent preservation of these deposits. This chapter compiles available instrumental, documentary, and geologic data on such deposits formed along the coast at 17°–18°S latitude and discusses the relationships that can be inferred between dated debris-flow deposits and the occurrence of El Niño events. The approach thus involves an analysis of temporal correlations between El Niño events, debris-flow episodes, and instrumental measurements of rainfall data during the last several decades. This analysis shows a weak statistical correlation between monthly or yearly rainfall amount and the warm phase of El Niño–Southern Oscillation (ENSO), but also that strong rainfall, sufficient to provoke debris flows, generally occurs during El Niño years. Documentary data from the last few centuries also tend to indicate that heavy rainfall episodes along the coast of southern Peru have commonly occurred during El Niño years, even though many El Niño years did not experience rains. We conclude that, for at least the last few centuries, El Niño conditions have been favorable for the formation of exceptionally short-lived but intense rainfalls, but that these conditions are not sufficient per se. Several regional and local meteorologic mechanisms and situations are apparently involved in the episodic occurrence of strong rainfalls and debris-flow activity along the coast of southern Peru.

Debris-flow activity during the early Holocene and at the end of the Pleistocene, when regional hydrologic conditions were different than at present, is more difficult to interpret in relation to ENSO. Unlike previous authors, we consider that debris-flow deposits formed prior to the mid-Holocene do not constitute strong enough evidence for past El Niño conditions. Similarly, we presume that lack of debris-flow evidence during a given time period cannot be taken as an indication that no El Niño events occurred during that period. Until we have a better understanding of the meteorologic processes driving exceptional intense rainfalls in the area and of the paleohydrologic regime, it would be misleading to infer the existence of El Niño, or La Niña, conditions from the existence of debris-flow deposits in this particular region.

The Relevance of Paleo-ENSO Studies

El Niño–Southern Oscillation, or ENSO, is the main source of global ocean climate variability on an interannual time scale. Understanding the variability of ENSO through geologic time is necessary to determine the boundary conditions that drive the phenomenon, to examine the interrelationships between this mode of ocean climate variability and other, longer-term sources of climate change, and to constrain coupled oceanic–atmospheric models. There is also strong societal interest in improved forecasting of El Niño events and in estimating the intensity and frequency of future ENSO events under conditions of global warming. Moreover, studies of the evolution of the dynamics of the ENSO trough time are necessary to better understand the influence of the ocean climate system on the development of different cultures around the world.

Because instrumental records have been maintained for only a short time, whereas climate modelers require longer-term records, there is a growing need for paleo-ENSO proxy records such as coral reef sequences, ice cores, dendroclimatic analyses, lacustrine and alluvial sedimentary sequences, beach ridge series, and, for the last few centuries, documentary data. These different proxy records generally aim to reconstruct the frequency and intensity of former El Niño events—the warm phase of ENSO. Up to now, however, none of these records by itself has yielded a complete series of El Niño occurrences. For instance, Quinn and collaborators (Quinn et al. 1987; Quinn and Neal 1992; Quinn 1993) provided historical El Niño sequences based on documentary data that have been widely used by ENSO researchers. But other researchers (Hocquenghem and Ortlieb 1992; Whetton and Rutherfurd 1994; Whetton et al. 1996; Ortlieb 1998, 1999, 2000; Ortlieb et al. 2002) have questioned the accuracy of many so-called reconstructed El Niño events between the sixteenth and the eighteenth centuries. This is not surprising, because some of the documentary data come from areas as far away as the Nile delta, China, and South America, where ENSO teleconnections are moderated by other atmospheric and oceanic processes. As a result, no consensus has been reached on a historical El Niño (or ENSO) chronological sequence prior to the instrumental record. At longer time scales the problem is still more acute, if for different reasons: the scarcity of high-resolution sequences, geochronological uncertainties, alteration or partial erosion of the records, and so on. In all cases, for very recent (documentary) or older (geologic) records, one particular problem must be addressed: Which regions record the former occurrences of the phenomenon with highest reliability? How can we be sure that a geographic area that today satisfactorily registers ENSO anomalies also did so in the past, under different regional and global circulation patterns?

El Niño Manifestations in Peru and Chile

The El Niño phenomenon was first identified in northern Peru, near the border with Ecuador (Carranza 1891), as the combination of an anomalous seasonal (summer) warming of the coastal waters and heavy rainfall in the desert of Sechura (4°–6°S). Later, it was observed along the coast of southern Ecuador to central Chile that the phenomenon is also characterized by a lowering of the thermocline and the nutricline and by a rise in sea level that may reach several decimeters within several weeks. The coast of northern Peru is where the El Niño phenomenon provokes the highest sea level rise (more than half a meter in 1982–1983), greatest seawater warming (up to 10°C at Paita, in 1982–1983), and greatest rainfall anomalies (locally up to 4,000 mm, compared to 100 mm mean). It is thus natural that this region is favored in the search for paleo-El Niño evidence (Quinn et al. 1987; DeVries 1987; Ortlieb and Macharé 1993; Macharé and Ortlieb 1993).

Another favorable area that faithfully registers the occurrence and intensity of ENSO manifestations is central Chile (Quinn and Neal 1983). Rutllant and Fuenzalida (1991) showed that at least since the end of the nineteenth century, the warm phase of ENSO is characterized by an excess of winter precipitation and the cold phase is generally marked by a deficit of rainfall. Over the last 120 years, for which there are reliable instrumental rainfall data, there is a good correlation between El Niño in northern Peru (during the austral summer) and central Chile (during the preceding austral winter) (Ortlieb 1998, 1999, 2000; Ortlieb et al. 2002). This coincidence reflects a teleconnection mechanism involving large-scale atmospheric processes in the eastern Pacific region (Caviedes 1981; Hastenrath 1985; Hamilton and Garcia 1986; Deser and Wallace 1987; Aceituno 1988, 1990; Philander 1991; Allan et al. 1996). It is because of this teleconnection that Quinn et al. (1987) and Quinn and Neal (1992) relied on documentary data on historical climatic anomalies from *either* central Chile or northern Peru to reconstruct past occurrences of El Niño events. However, Ortlieb and co-authors (Ortlieb 2000; Ortlieb et al. 2002) noted that before 1817, very few heavy rainfall events reconstructed from documentary evidence from northern Peru and central Chile did coincide in time. Ortlieb (1997, 1998, 2000) thus suggested that the teleconnection mechanisms had possibly been affected by other modes of climatic variability, such as those related to the Little Ice Age. This hypothesis remains to be further tested, for example, by comparing with data from tropical ice core and coral reef sequences. Meanwhile, it is plausible that the regional teleconnections observed today may not have been operating in past centuries and millennia.

When Did the El Niño Phenomenon Appear in Peru?

In the last few decades, there has been some discussion regarding the onset of the El Niño system of climate variability in Peru. Sandweiss and co-authors (Sandweiss 1986; Rollins et al. 1986; Sandweiss et al. 1983, 1996, 1999) proposed that no ENSO manifestation was recorded in Peru before the mid-Holocene and supported the hypothesis that the onset of the El Niño occurred at about 5000 B.P. This interpretation relied heavily on observations that some warm-water mollusks occurred in different localities prior to 5000 B.P. (noncalibrated age) along the coast of north-central Peru. The mentioned authors suggested that a large reorganization of the ocean-atmosphere circulation system in the eastern Pacific took place during the mid-Holocene. They claimed that prior to 5000 B.P., the coastal waters of that area were significantly warmer than today, and that after the mid-Holocene, the boundary between the cold Humboldt (Peru) Current and the warm equatorial waters would have moved northward by about 500 km, to reach its present position (at about 5°S).

Other researchers (DeVries and Wells 1990; Díaz and Ortlieb 1993; Perrier et al. 1994; Béarez et al. 2003) have not shared the interpretation that coastal waters were warmer in the past in north-central Peru and instead have argued that the warm-water molluscan species were all lagoonal forms that lived in protected, marginal lagoons that provided a higher temperature than the open ocean. Other biological proxy data also failed to support the theory of a major shift of the boundary between the cool Humboldt domain and the warm equatorial waters. Perrier et al. (1994) showed through stable isotope serial analyses that *Trachycardium* shells from north-central Peru dated to 5500 B.P., 5800 B.P., and 6100 B.P. contained growth irregularities similar to those observed today in response to El Niño events, registering short-term thermal anomalies of the water that amounted to several degrees C (like those recorded after the very strong 1982–1983 El Niño event). Furthermore, DeVries et al. (1997) argued that it was precisely because the El Niño system already existed before 5000 B.P. that the lagoons which formed during mid-Holocene maximum sea level, near 7000 B.P. (Wells 1988), could be fed episodically with larvae of warm-water species that normally live in the Panamic molluscan Province (i.e., north of 6°S). Similar conditions of lagoonal environments that previously enabled the survival of extralimital warm-water species have also been found in deposits of prior interglacial stages in southern Peru and northern Chile (Ortlieb et al. 1990, 1996; Díaz and Ortlieb 1993; Guzmán et al. 2001).

Recently, additional terrestrial proxy data have tended to indicate that El Niño extended back to the end of the Pleistocene, although with different characteristics. Rodbell et al. (1999) reported data from a high-elevation Andean lake in southern Ecuador, whereas Keefer et al. (1998) presented data from alluvial and debris-flow deposits in southern Peru (Fig. 1). Both studies suggest that ENSO mechanisms were not restricted to the second half of the Holocene. However, both studies relied on an interpretation of alluvial processes in two quite different depositional environments, and both assumed that present-day hydrologic phenomena linked to ENSO were also operative at the end of the Pleistocene and in the early Holocene.

Here we evaluate interpretations of climatic significance of alluvial deposits formed in the southernmost part of the Peruvian coastal desert. To what extent can we assume, as Keefer et al. (1998) did, that remnants of debris flows and floods in the coastal region of southern Peru were related to El Niño conditions in the latest Pleistocene and early Holocene times? The relationships between paleo-ENSO impacts and alluvial and debris-flow deposits in the area will be analyzed at different time scales with different kinds of data: (1) for the last half-century, using instrumental measurements; (2) for the last few centuries, based on documentary sources; and (3) for the last 12,000 years, using radiocarbon-dated geologic deposits. Recently acquired data from southern Peru are presented and discussed with respect to other published El Niño proxy data (Keefer et al 1998; Fontugne et al. 1999).

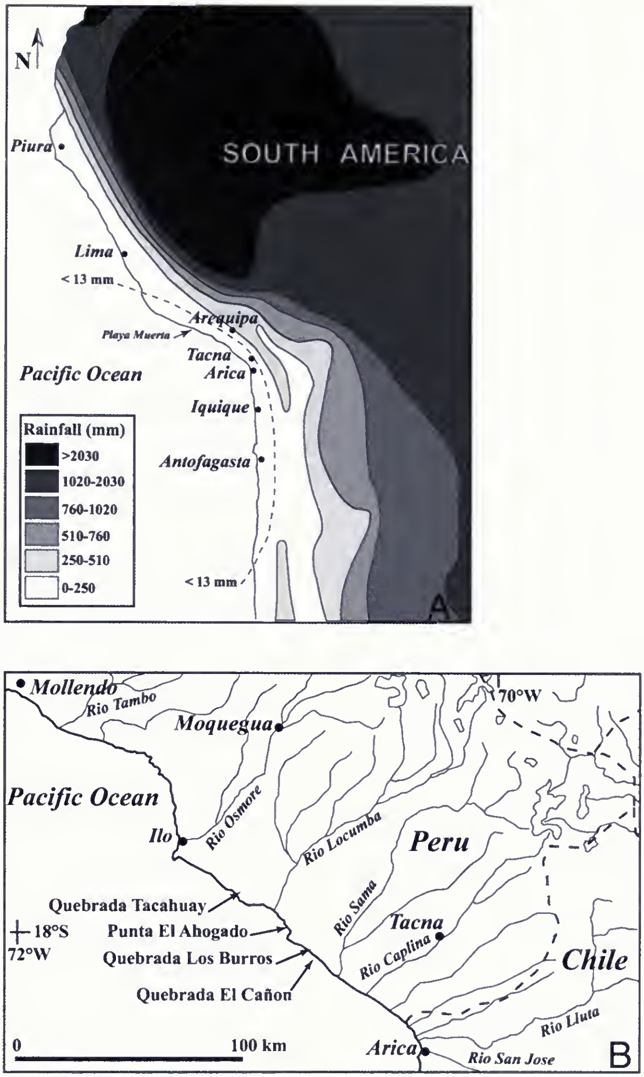

Figure 1. **A.** Location of sites studied in southern Peru and northern Chile, with indication of mean interannual rainfall (modified from Kendrew 1961). **B.** Details of the coast of southernmost Peru, with localities studied.

El Niño Impact on Rainfall and Debris-Flow Events in Southern Peru During the Second Half of the Twentieth Century

El Niño and Rainfall Anomalies in Peru

After the very strong 1982–1983 El Niño event, which was characterized by a severe drought in the southern half of Peru and on the Bolivian Altiplano, many authors (e.g., Huaman Solis and Garcia Peña 1985; Francou and Pizarro 1985; Garcia Peña and Fernández 1985; Ropelewski and Halpert 1987; Thompson et al. 1984) considered that the precipitation deficits in this area were typical of El Niño conditions. At present it is considered that the relative drought that was observed during El Niño years may be more specific to the Andean part of southern Peru, and not precisely specific to the coastal region of southern Peru (Rome-Gaspaldy and Ronchail 1998). Recent analyses of instrumental rainfall data from the second half of the twentieth century confirm that the positive rainfall anomalies over the coastal regions of Ecuador and northern Peru exhibit the only statistically significant correlation with El Niño events within the region encompassing Ecuador, Peru, and Bolivia (Aceituno 1988; Rossel 1997; Rome-Gaspaldy and Ronchail 1998; Rossel et al. 1998). Analysis of monthly rainfall data between 1960 and 1990 indicates that only the coastal area of northern Peru (Piura region) shows a positive correlation between rainfall and the warm phase of ENSO, and intensified drought during the cold phase of ENSO (La Niña) (Rome-Gaspaldy and Ronchail 1998). More specifically, no clear correlation between rainfall anomalies and ENSO (either the El Niño or the La Niña phase) has been observed for the southern Peru region (Minaya 1994; Rome-Gaspaldy and Ronchail 1998). The very strong 1982–1983 El Niño event was characterized by intensified drought in Arequipa and a strong deficit of the Majes River flow (17,058 km^2 watershed, 450 km long, spring at 4886 m on the western flank of the Andean Cordillera), but other strong El Niño events, such as the 1972–1973 event, were marked by exceptional rainfall at Arequipa and maximum flows of the Majes River (Minaya 1993, 1994) (Fig. 2). These inconsistencies are linked to complex climatic mechanisms operating in this particular region involving a variable position of the Intertropical Convergence Zone, substantial differences in the atmospheric circulation patterns during different ENSO events, and interactions between the coastal area and the cordilleran zone.

Debris-Flow Episodes and Strong Rainfalls in Southern Peru

In arid countries, debris-flow activity is tightly linked to the occurrence of relatively intense rainfalls. In the Chile–Peru coastal desert, debris-flow activity may be observed with precipitation amounts above 20 or 30 mm, and after rainfall episodes that last more than 3 hours (Vargas et al. 2000).

The occurrence of heavy rainfall episodes, debris flows, and inundations of the coastal region of Tacna (southern Peru) was compared with available monthly rainfall data, information obtained from local newspapers, and ENSO indexes for the period 1960–2000. The mean annual rainfall at Tacna for this period was 19 mm. The total annual rainfall data and the annual mean Southern Oscillation Index (SOI) do not show any significant correlation. However, a coincidence between years with an excess of rainfall and low values of SOI (Fig. 3) was observed. On the other hand, not all the years characterized by low SOI values exhibit an annual excess of rainfall. Between 1960 and 2000, there were 11 "rainy" months (rainfall > 19 mm per month). Three of them (September 1960, September 1961, and September 1962, with 20.2, 34.6, and 33.0 mm of total accumulation, respectively) do not correlate with El Niño events (as defined by Trenberth 1997). For the rest of the cases (January 1983 and January 1998, with respectively 24.0 mm and 21.2 mm total rainfall; July 1963 and July 1972, with respectively 32.0 mm and 59.0 mm total rainfall; September 1963, September 1965, and September 1997, with respectively 33.1, 22.6, and 31.7 mm total rainfall; and December 1997, with 28.2 mm of total rainfall), a correlation is observed with El Niño events as defined by Trenberth (1997). During La Niña episodes, an excess of precipitation events has not occurred.

Information published in local newspapers in Tacna allows a historical reconstruction of the heavy rainfall episodes and debris flows in this region for the last 40 years (Table 1). In the 11 months with heavy rainfall previously mentioned, debris flows occurred in January 1983 and September 1997, and to a lesser extent in July 1972 and January 1998. In these cases, the heavy rainfall episodes occurred during El Niño events of strong intensity, characterized by low SOI values and important anomalies of the sea-surface temperature at Puerto Chicama (Table 1, Fig. 4). The chronicles indicate a great spatial variability in the total amount of precipitation related to the strong convective character of the storms. During these heavy rainfall events, as was shown for the coast of northern Chile by Vargas et al. (2000), the rain frequently occurred at night.

A similar relationship between heavy rainfall, debris flows, and El Niño events was determined for the coastal area of the Atacama desert, and particularly at Antofagasta (23°S), in northern Chile (Vargas et al. 2000). In northern Chile, not all El Niño events provoke "heavy" rainfall episodes, but all the events able to produce debris flows (rain intensity > 20 mm/3 hours; Hauser 1997; Vargas et al. 2000) occurred during the development phase of El Niño events, in the austral winter (Rutllant and Fuenzalida 1991; Garreaud and Rutllant 1996). In

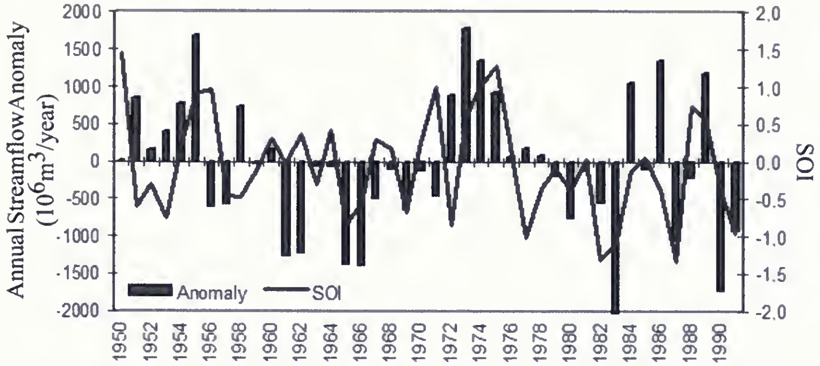

Figure 2. Comparison of annual streamflow anomalies of Majes River (southern Peru) and variation in the Southern Oscillation Index (SOI) during the 1950–1991 period (streamflow data from Corporación de la Aviación Civil, CORPAC, in Minaya 1994). No clear-cut correlation is observed between El Niño (negative SOI values) or La Niña (positive SOI values) and the Majes River streamflow.

1925, 1930, 1940, 1982, 1987, and 1991, heavy rainfall episodes in northern Chile were linked to storms coming from mid-latitude regions.

In the coastal area of southern Peru, the climatic mechanisms involved in the generation of "heavy" rainfall events are not yet totally understood. While debris-flow events related to heavy rainfall episodes were contemporary with strong El Niño events (Fig. 4), some of them occurred during the austral summer (January 1983 and January 1998), while others occurred during the austral winter or spring (July 1972 and September 1997). The strong rainfall events occurring in the coastal area during the austral summer should be linked to the activity of the rainy season on the Altiplano and the cordillera. Those occurring in winter during El Niño years are not clearly understood and cannot be readily related to the same processes described in northern Chile (frontal systems coming from mid-latitude regions).

Because the reliable instrumental data cover a relatively short time period, we investigated the relationship between regional strong rainfalls and ENSO during the last few centuries.

Historical Rainfall Data and El Niño Manifestations During the Last Four Centuries

Documentary data on climate in Peru and Chile were largely used by Quinn et al. (1987), Quinn and Neal (1992), Hocquenghem and Ortlieb (1992), and Ortlieb (1999, 2000) to try to establish a sequence of El Niño events during the last few centuries. Documentary sources consist of reports on droughts, river flooding, the destruction of bridges and buildings, good and poor crops, heavy storms, and other impacts of meteorologic conditions. Information was obtained from a variety of official, ecclesiastical, and particular documents left by the Conquistadores and the later inhabitants of these regions during colonial times and after independence from Spain. These data led to different interpretations by the above-mentioned authors. Whereas Quinn tended to interpret reports of storms and heavier rainfall than usual along the coastal desert of Peru or in central Chile as evidence of past El Niño conditions, Ortlieb (2000) considered that only information on precipitation excess in coastal northern Peru and in central Chile could be reliably used as an El Niño indicator. Hocquenghem and Ortlieb (1992) and Ortlieb (2000) argued that, based on instrumental records of the last decades, Rimac River floods (in Lima) and unusual vegetation cover along the coast of southern Peru should not be taken by themselves as evidence of El Niño conditions. Unusual vegetation growth in the *lomas* (hilltops) in the area of Ilo could be due to intensified winter *garuas* (coastal fogs), not necessarily to strong rainfall. In some cases it was shown that droughts in coastal northern Peru were coeval with vegetated *lomas* in southern Peru, probably during La Niña conditions.

Previous work on documentary sources on climate anomalies in the Norte Grande of Chile showed that reliable data for the scarcely in-

TABLE 1. Compilation of precipitation anomalies in the Tacna area and southernmost Peru (newspaper sources) for the period 1960–2000. Total monthly rainfall from SENAMHI (Peru).

Newspaper source	Day of occurrence	Duration and amount of rainfall	Effects at Tacna and its coastal area	Effects in the Andean area	Monthly rain-fall (mm) at Tacna
1961, Sept. 5, *La Voz de Tacna*	Sept. 4	Continuous and intense rainfall from 3 p.m.; 7.5 mm	Tacna: inundations, roof collapses		34.6
1962, Sept. 18, *La Voz de Tacna*	Sept. 18	Intense rainfall	Tacna: inundations and roof collapses		33.0
1963, Sept. 13, *Correo del Sur*	Sept. 12	Intense rainfall and strong winds from 12 a.m. to 6 p.m.; 5 mm	Tacna: inundations	Heavy rainfalls over the Tarata region.	33.1
1965, Sept. 5, 7, *La Voz de Tacna*	Aug. 29–Sept. 4	Weak rainfalls: 90 hr in 1 week	Tacna: inundations and roof collapses		22.6
1972, July 5, 7, 8, *Correo*	July 3–4	Heavy rainfall during the night	Tacna: inundations		59.0
	July 5–8	Continuous rainfall	Tacna: inundations		
1972, July 21, 22, 24, *Correo*	July 20–23	Weak rains, intense rainfalls occasionally	Tacna: inundations, roof and wall collapses		
1983, Jan. 9, *Correo*	Jan. 7–8	Heavy rainfall during the night from 7 to 8 a.m.	Ite: *Huaycos* at 11 p.m. (Jan. 7), damages. Inundations in Ite. *Huayco* in "Ite-Norte" project. *Huaycos* in several points of the Ite-Boca del Rio road. Five *huaycos* in the road to Pocoma.	Rains at Ilabaya.	24.0
1983, Jan. 10, 11, *Correo*	Jan. 10–11	Persistent rains	Rainfall at Ite and other coastal areas. *Huaycos* and damage in several places of the Boca del Rio-Vila Vila-Ite Meca road.		
1983, Jan. 14, 15, *Correo*	Jan. 13–14	Heavy rainfall beginning at 6 p.m. with weaker rains later at night; rainfall between 10 p.m. and 3 a.m. (Jan. 14) in the suburbs of Tacna		Rainfalls in the Andean area of the Tacna region.	

TABLE 1. *Continued.*

Newspaper source	Day of occurrence	Duration and amount of rainfall	Effects at Tacna and its coastal area	Effects in the Andean area	Monthly rain-fall (mm) at Tacna
1983, Jan. 26, *Correo*	Jan. 24–26	Intense rainfall followed by weak rains	Tacna: inundations, roof and wall collapses. *Huaycos* at Ite and in the Ilo-Boca del Rio road during the night (Jan. 13). 50 m of vertical erosion in Quebrada Tarampilla. Destruction of the Tarampilla bridge.	Rainfalls in the Andean area of the Tacna region.	
1997, Sept. 15, 16, *Correo*	Sept. 14	Intense rainfall followed by weak rains at Ilo; weak rains at Tacna for 1 week	Tacna: inundations, roof and wall collapses. Vegetation in *lomas* at Ilo. *Huayco* (1.5 km width and 1.5 m high) in the coastal road at Quebrada Los Burrows. Damage in Vila-Vila and Morro Sama.	Drought in the Andean zones of southern Peru: Puno, Cusco, Arequipa, and pre-Andean zones of the Moquegua and Tacna regions.	31.7
1997, Sept. 18, 22, 29, 30, *Correo*	Sept. 18–29	Weak rains; weak rains and low temperatures at Ilo	Tacna: inundations and wall collapses. Vegetation growth in the lomas of Sama-Las Yaras (coastal area).		
1998, Jan. 6, 7, 8, *Correo*	Jan. 4–5	Intense rainfall during the night of Jan. 5	Los Palos and Santa Rosa (coastal area): intense rainfall and strong winds (50 km/hr)	Heavy rainfalls during the night. *Huaycos*, inundations, and overflow of rivers in the Andean zones. Landslides and inundations at Tarata.	21.2
1998, Jan. 12, 15, 21, 22, 26, 27, *Correo*	Jan. 12 Jan. 13–26	Continuous rainfalls at Tacna	Tacna: inundations, collapse of building roofs	Strong rainfalls, *huaycos*, inundations, and overflow of rivers in Andean zones.	

Note: *Huayco* (*huaico*) = landslide, debris-flow deposit.

TABLE 2. Documentary record (with indication of historical sources) of some heavy rainfall events and debris-flow activity in the coastal regions of southern Peru and northern Chile during the last few centuries (prior to 1925), and their possible relationship with former El Niño episodes, as reconstructed by various authors.

	Reports on rainfall events and debris-flow activity on the coast of:			**Corresponding El Niño/La Niña occurrences,* according to:**		
Year	**Southern Peru**	**Northern Chile**	**Sources and references**	**Quinn et al. 1992**	**Ortlieb 2000**	**Ortlieb et al. 2002**
1619	Rainfall and thunderstorm at Ilo in June		Cobo 1653 (1964:1:90)	1618–19: S	1618–19: M?	1619: M?
1634	Floods in S Peru in Feb.–Mar.	Flooding in Arica in Mar.	Suardo 1629–39 (1936: 2: 13–15)	1634–35: S	—	—
1745–1752	Rainstorms in S Peru and repeated debris-flow activity in Locumba valley; rainstorms in Moquegua in March 1747		Llano y Zapata 1748:2–3; Larrain 1974:143; Couyoumdjian & Larrain 1975: 345	1747: S+ 1750: M+	1747–48: S 1750: —	1747: — 1748: VS 1751: *LN?*
1830		Flooding of Rio Azapa in Arica in April, probably related to cordilleran rains	D'Orbigny 1830 (in Wormald Cruz 1972:22)	—	—	1830–32: *LN*
1857	Large floods in Moquegua		Labarthe 1914:315	1857–58: M	1857: M?	—
1860	Rainfalls in Moquegua and Arequipa in Feb. 1860		Labarthe 1914:315–316	1860: M	1860: *LN?*	1860: M
1877–1878	Rains (during 14 (?) months in 1877–78) and floods in Mollendo and S Peru. Unusual vegetation in S Peru.	Rains and floods in Pampa del Tamarugal in Jan. 1877 and in June 1878; rainfall in Caracoles in Aug. 1877	Basadre 1884:44; Billinghurst 1886:36; Melo 1913 (156); Bowman 1924:42; Urrutía y Lanza 1993:124	1877–78: VS	1877–78: VS?	1877: VS 1878: M
1884	Rains and floods at Moquegua, Tacna and Ilo in Feb.	Major floods in N Chilean rivers and in Pampa del Tamarugal (Quebrada Quisma) in Jan.–Feb.	Billinghurst 1886:36; Labarthe 1914:317–318; Bowman 1924:42; Alfaro Calderón 1936:519; Klohn 1972:103; Urrutía y Lanza 1993:128	1884: S+	1884: S	1884: M?
1898	Flooding of Tambo, Vitor, Majes, and Osmore (Ilo) Rivers		Labarthe 1914:319–320	—	—	—
1899	Flooding of Tambo, Vitor, and Moquegua Rivers in Feb.		*El Comercio* 1899 (Feb. 17, 22, 24, 25)	1899–1900: S	1899: S? 1900: —	1899: S

TABLE 2. *Continued.*

Year	Reports on rainfall events and debris-flow activity on the coast of:		Sources and references	Corresponding El Niño/La Niña occurrences,* according to:		
	Southern Peru	Northern Chile		Quinn et al. 1992	Ortlieb 2000	Ortlieb et al. 2002
1911	Flooding in Tacna in Feb. Grass cover in Mollendo area in Nov.	Flooding in Pampa del Tamarugal in Feb.	Bowman 1924:42, 52; Urrutía y Lanza 1993:174–175	1911–12: S		(1911: *LN*)
1918	76 hr rainfall in Dec. and "flowering desert" in S Peru	Rainfall in Arica (10 mm) in Jan.	Almeyda 1948:85; Gierke 1985:15; Chapman 1918 in Murphy 1926:120–121, but data questioned by Petersen 1935:2:28–31	1917: S 1918: —		—
1925	Rainfalls at Tacna (70 mm), with peaks in Aug.–Sept.	Rainfall in Iquique-Antofagasta region, flooding in Antofagasta in July	Almeyda 1948:86, 90–93; Vargas et al. 2000:167	1925–26: VS		1925: — 1926: M

* VS (very strong), S (strong), and M (moderate) refer to the inferred intensity of the former El Niño events; *LN?* refers to possible La Niña events.

habited Atacama desert were for practical purposes limited to the last two centuries (Ortlieb 1995). However, some additional and fragmentary data from northernmost Chile and southern Peru have recently turned up (Ortlieb 2000). Table 2 presents data gathered on unusual rainfall and debris-flow activity in the coastal areas of southern Peru and (present-day) northernmost Chile (north of 23°S) since the earliest documentary record, dated 1619. Information on heavy rainfalls in the central depression of northern Chile, and floods in the *quebradas* coming from the cordillera, which are linked to La Niña conditions in the Altiplano and the Andean Cordillera, were not considered (unless they co-occurred with precipitation anomalies along the coast). The precipitation excesses are compared with past occurrences of El Niño (or La Niña) events as proposed by Quinn and Neal (1992), Ortlieb (2000), and Ortlieb et al. (2002). The last three columns of Table 2 do not contain all the reconstructed El Niño (and La Niña) events (according to the cited authors) but only those that are contemporaneous with the hydrologic anomalies indicated in the first two columns at left.

Table 2 shows that most heavy rainfall episodes and debris-flow activity registered in the coastal study area occurred during El Niño years, as determined by either one or all of the cited authors. Several cases of flooding of the San José or Azapa Rivers at Arica are not related to rainfall in the coastal area but reflect precipitation excess in the Andean Cordillera, during La Niña (or normal) conditions.

The historical data presented here cannot be regarded as definitive, for several reasons. First, documentary data are inherently fragmentary and subject to error, exaggeration, and misinterpretation. Second, we still lack a reliable chronological sequence of El Niño occurrences, as evidenced by conflicting accounts in the last three columns of Table 2. Third, the information on river floods does not always show the effects of cordilleran versus coastal rains. Rainfall in the upper part of the watersheds, in both southern Peru and northern Chile, follows different regimes and has quite different mechanisms from precipitation in the coastal areas. Nevertheless, the historical data presented in Table 2 tend to confirm that in a longer term than the last few decades, precipitation excess in the studied coastal area was generally observed during El Niño years, and that El Niño

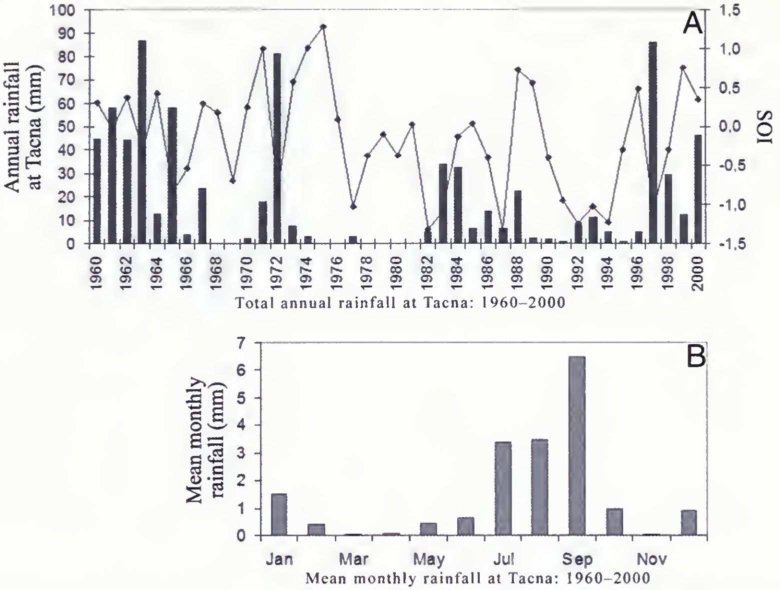

Figure 3. **A.** Comparison of total annual rainfall at Tacna and SOI during the 1960–2000 period (monthly rainfall data from SENAMHI, Peru). **B.** Distribution of the mean monthly rainfall at Tacna for the same period.

conditions do not systematically induce rainfall excess in the study area.

During the last centuries, as during the last decades, intense rainfalls and debris-flow activity often occurred during El Niño years, but the relationship is not as tight as for the coast of northern Peru. The "intense" rainfalls on the coast of southern Peru are linked to convective features, which may be favored by one or another side effect of the anomalous patterns of atmospheric circulation induced by ENSO in the region.

The Latest Pleistocene/Early Holocene Debris-Flow Episodes

Several localities on the coast of southern Peru recently yielded new data on the age of late Quaternary debris flows. Most of the radiocarbon data was obtained from material of anthropic origin: charcoal fragments, organic matter, and marine shells. One study (Keefer et al. 1998) has addressed the sequence of latest Pleistocene–early Holocene alluvial deposits on the bank of the deeply incised Quebrada Tacahuay, 40 km south of Ilo (see Fig. 1B). In another study, Fontugne et al. (1999) examined the alluvial sequence at Quebrada Los Burros, 30 km to the south of Tacahuay. In between, near Punta El Ahogado, a sequence of debris-flow deposits yielded a new radiocarbon data set.

A comparison of the geomorphic contexts and chronological data at these three localities may provide insight into the geologic and paleohydrologic processes during the Pleistocene–Holocene boundary and in the first half of the Holocene. The following discussion considers to what extent the debris-flow units may be related to former occurrences of the El Niño phenomenon.

The Quebrada Tacahuay Sequence

Keefer et al. (1998) Data. In a locality south of Ilo, on the northern bank of Quebrada Tacahuay (17°50′S, 71°07′W), Keefer et al. (1998) studied a geologic section atop an inland alluvial fan that encompasses the late Pleistocene–mid-Holocene period. The section exposes 19 debris-flow and flood deposits, with the most recent of them bearing remains of human occupation (including charcoal fragments, bird bones, and a few marine shells) (Fig. 5). Keefer et al. (1998) distinguished four periods in this sequence:

- Before an archaeological horizon at 12,700

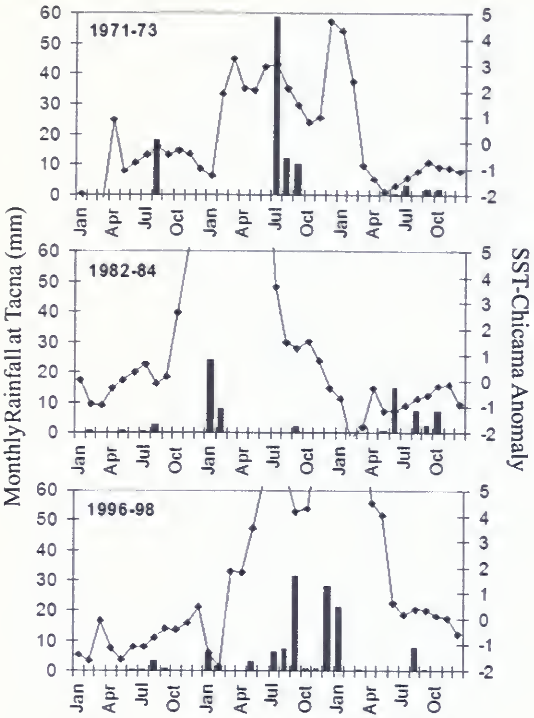

Figure 4. Total monthly rainfall at Tacna and sea-surface temperature anomalies at Puerto Chicama for periods with occurrence of debris-flow events or inundations along the coast of southern Peru.

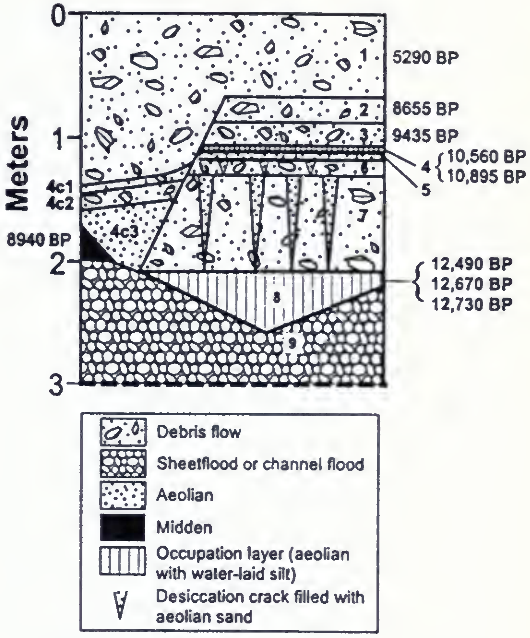

Figure 5. Composite stratigraphic sequence of the Quebrada Tacahuay, south of Ilo (from Keefer et al. 1998). Ages are expressed in calibrated years (cal. B.P.). Units K1, K2, K3, K4c1, K4c2, K6, and K7 are described as debris flows. Unit K8 is the main occupation layer. Radiocarbon data from this sequence are shown in Table 3.

cal. B.P., a sequence of eight debris-flow deposits, three aeolian sand layers, and two major flood units. From an infrared-stimulated thermoluminescent (TL) dating at 38.2 ka at the base of this sequence, Keefer et al. (2001) later inferred that these 10 debris-flow and alluvial events occurred between 38,200 ka and 12,700 cal. B.P.

- Between 12,500 cal. B.P. and about 8800 cal. B.P., four extensive debris-flow deposits were formed (their units 2, 3, 6, and 7 [see Fig. 6], which we will refer to here as K2, K3, K6, and K7).
- Between 8800 and 5300 cal. B.P., they recognized one debris-flow unit, which can be subdivided into two thin layers (subunits K4c1 and K4c2, observed in a single profile) overlying an aeolian sand unit (K4c3).
- At ca. 5300 cal. B.P. (= 4550 ± 60 B.P.) one last major debris-flow deposit (unit K1) formed just before the main channel of Quebrada Tacahuay began to be incised.

Presently, the floor of Quebrada Tacahuay lies about 30 m below the top of the sedimentary sequence. This sequence, cut by the paved coastal road, is located about 1 km inland from the shoreline.

In their study, Keefer et al. (1998) emphasized the archaeological aspects of their findings. The major and oldest human occupation was dated to 12,700–12,500 cal. B.P. and was apparently interrupted because of the occurrence of a large debris flow (unit K7; see Fig. 5). The archaeological remains, including a well-preserved hearth, which are found in a 10- to 50-cm-thick layer of water-laid silt, with interstratified lenses of aeolian fine sand (unit K8 in Fig. 5), are atypical because they include very few marine shells, abundant seabird bones, some remnants of pelagic fishes, and a few lithic artifacts.

Our Data. During a brief visit to this locality (in 1998), observation and sampling were conducted in the southwestern part of the area studied by Keefer et al., to the west of the road. Figures 6 and 7 show the studied sequence,

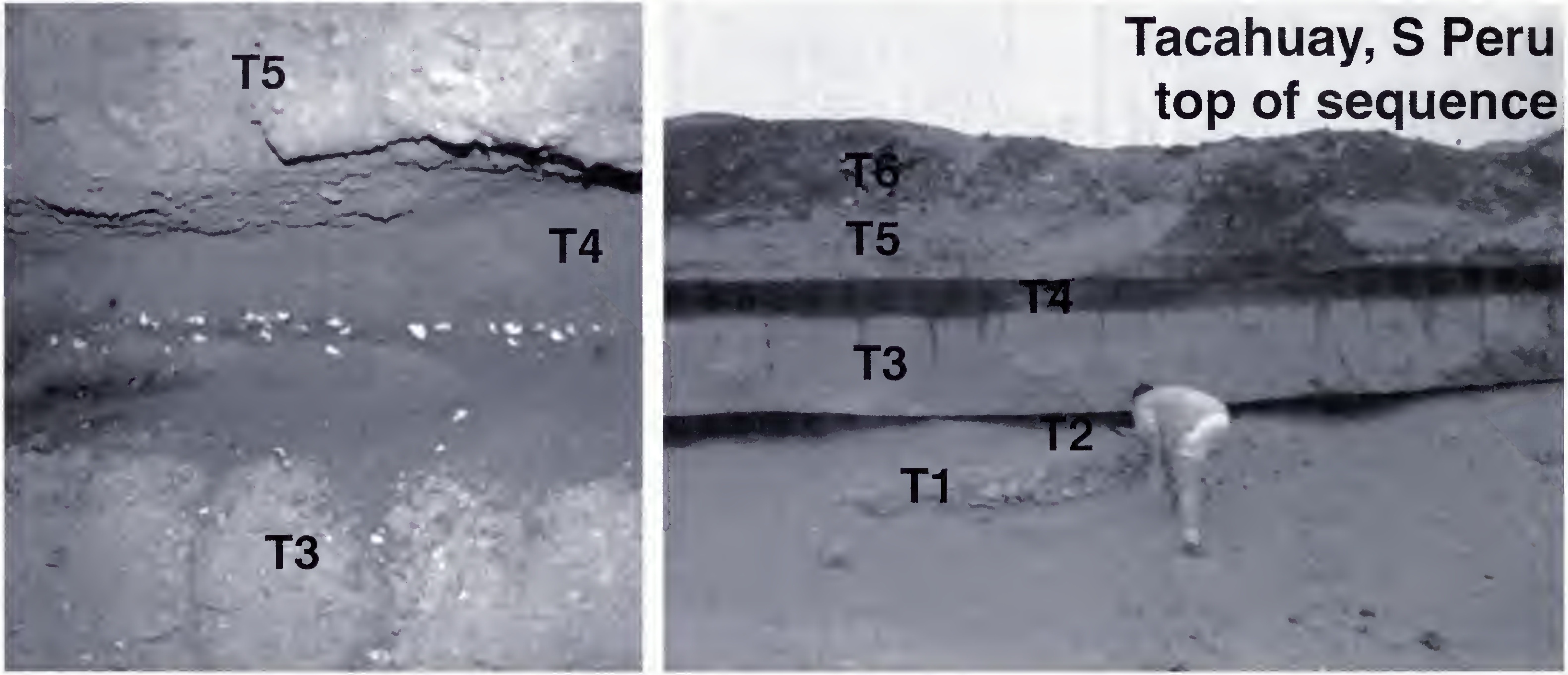

Figure 6. Top of the Late Quaternary sequence of alluvial and debris-flow deposits in Quebrada Tacahuay (southern Peru) previously studied by Keefer et al. (1998) (Fig. 5). The sandy fossiliferous units T2 and T4, which include anthropic charcoals, yielded additional radiocarbon data (see Table 2). Units T1 and T6 are equivalent to units K9 and K1, respectively, of Keefer et al. (1998).

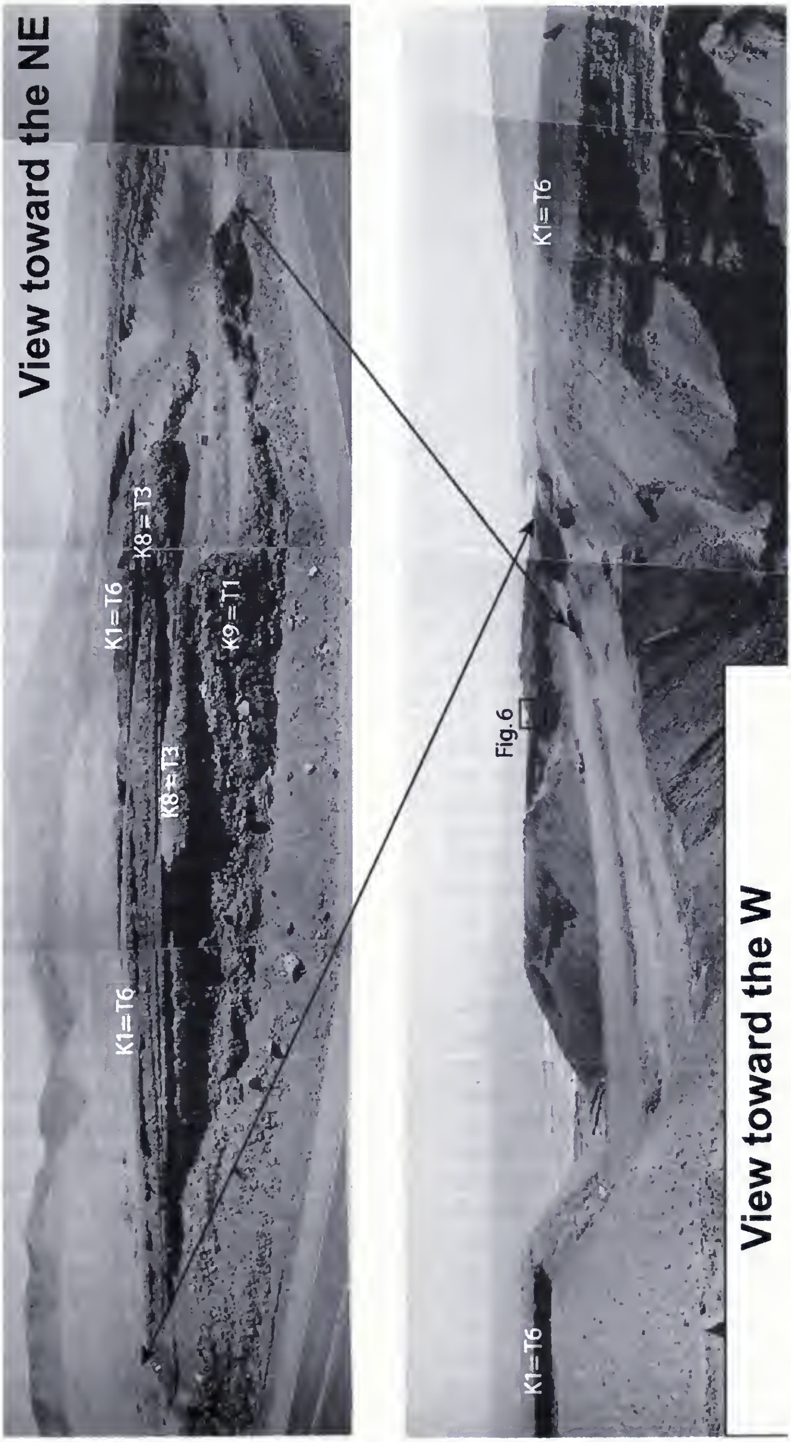

Figure 7. Panoramic views of alluvial sections at Quebrada Tacahuay in southern Peru. Locale of Figure 6, as well as some debris-flow and sheet flood deposits, are indicated.

with units numbered T1 to T6 from bottom to top. The upper layer, designated T6 (equivalent to unit K1 of Keefer et al. 1998) is a thick debris-flow deposit that is colored dark by abundant organic matter. Below it occur (from top to bottom) a composite debris-flow deposit (T5), an alluvial (sheet flood) unit (T4), another debris-flow unit (T3), a composite alluvial layer (T2), and a coarse fluvial conglomerate (T1). Radiocarbon data (Table 3) were obtained on the two alluvial layers T2 and T4, both water-laid deposits that incorporate a high amount of reworked aeolian sand. Unit T4 contains charcoal fragments, seemingly related to washed-out hearths; marine shells brought by man; and abundant terrestrial gastropods (not necessarily linked to a human occupation). This unit T4 includes remnants of a relatively young phase of human occupation dated to about 9000 cal. B.P. and referred to as "the shell midden" by Keefer et al. (1998). Unit T2, which is practically devoid of marine shells and contains many bird bones, is the major "occupational" layer of Keefer et al. (1998)—that is, their unit K8.

Our chronological data and those of Keefer et al. are presented in Table 3.

Paleohydrologic and Paleoclimatologic Interpretations. The Quebrada Tacahuay sequence thus consists in a succession of alluvial and sheet flood units, debris-flow deposits, and aeolian sand units. The water-laid sediments can be separated in two categories: the alluvial units, which were deposited in the bed (or the banks) of the Tacahuay river, and the debris-flow and sheet flood units, which are linked to superficial runoff, not necessarily within the valley. The dark brown (T6) or reddish (T5 and T3) colors of the debris-flow units (Fig. 6) result from the proportions of clay, silt, and reworked soil in the matrix; the larger size components may be subrounded to angular. The alluvial units are generally gray or yellowish; their matrix is coarse-grained, and they include pebbles and blocks of varying size, which may be rounded to subangular. The sheet flood deposits generally consist of thin layers or lenses of sands that show current figures, laminations, cross-bedding structures, and the like. They may include layers bearing reworked material (shells, bones, charcoal fragments).

The petrographic composition and the shape of the coarse elements found in the thickest alluvial units of the sequence clearly indicate that the material comes from upstream in the relatively large watershed of the Quebrada Tacahuay. Because the watershed is of limited size, there is no doubt that the hydrologic regime was controlled by rainfalls in the coastal region. The >25-m-thick sequence of (mainly) alluvial deposits that predate the T1/K9 unit (Fig. 7) corresponds to a late Pleistocene episode of active, aggrading, sedimentation processes. It is inferred that the hydrologic regime was controlled by regular and abundant rainfalls. The scarcity of chronological data from the Pleistocene sequence (besides the 38.2 ky TL date obtained by Keefer et al. 2001) hampers any precise paleoclimatic and paleohydrologic interpretation.

The debris-flow units are mainly formed from superficial material eroded from the topographic surface, including interfluves and nearby hill slopes. The formation of these deposits implies that relatively strong and intense rainfalls occurred in the immediate vicinity of the outcrops. The debris-flow units have a limited lateral extension. As shown in Figure 7, the debris-flow unit T6/K1 formerly extended on both northern and southern sides of the present-day thalweg of Quebrada Tacahuay. This observation provides a maximum age (5290 cal. B.P.) for the beginning of the incision of the *quebrada* at this locality. We surmise that the downcutting of the thalweg responded more directly to retrogradation processes of the incision related to the mid-Holocene high sea level than to paleoclimatologic factors. Sometime around 5000 cal. B.P. linear erosion took over the upward aggradation processes, at this locality relatively close to the coastline. We interpret that it was not precisely because of a variation in the hydrologic regime that the thalweg was formed and progressively entrenched. This is not easy to demonstrate because the erosive processes dominated during the second half of the Holocene, and thus no subsequent sedimentary deposit was preserved in this locality. In other words, the morphologic evolution of the locality during the late Holocene prevents us from making any comparisons between present (or recent) hydrologic conditions and those that existed prior to the mid-Holocene.

Keefer et al. (1998) interpreted as evidence for El Niño manifestations the half-dozen episodes of debris-flow events (units K7 to K1, Fig. 5) identified between 12,500 and 5300 cal. B.P. They further suggested that, because of the

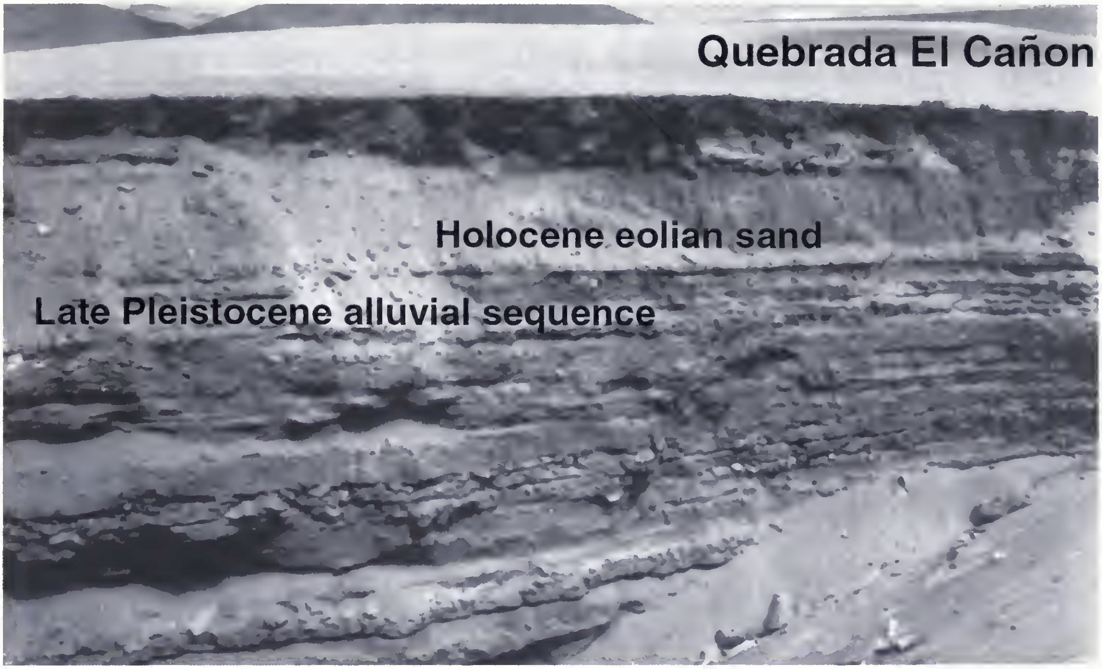

Figure 8. Late Pleistocene coarse alluvial units overlain by an early Holocene sandy layer and by a late Holocene occupational horizon (sand and silts with abundant charcoal and ceramic fragments) in Quebrada El Cañon, about 1 km south of Quebrada Los Burros, southern Peru. The Pleistocene alluvial units are most probably coeval with those of Quebrada Tacahuay and with the oldest debris-flow deposits of Punta El Ahogado.

sedimentologic similarity between these debris-flow deposits and those that predate unit K8 (i.e., older than 12,700 cal. B.P.) in the sequence of Quebrada Tacahuay, El Niño conditions were also present during the late Pleistocene. These interpretations are essentially based on the assumption that, as at present, violent rainfalls in this coastal area would characteristically have occurred during El Niño years.

We disagree with the interpretations of Keefer et al. regarding the character of ENSO proxies of the debris-flow units. Too little is known about the morphoclimatic and paleohydrologic local conditions at the end of the Pleistocene in the Tacahuay region, and more generally in coastal southern Peru. The superposition of sheet flood, debris-flow, and alluvial sediments has no modern equivalent and does not represent climatic conditions comparable to present conditions. Instead, the abundance of alluvial layers for the late Pleistocene part of the Tacahuay sequence suggests a more humid climate, with stronger and more regular flow episodes, than in the late Holocene. If this was the case, there is no reason to infer that debris-flow activity was linked to El Niño conditions.

Quebrada Los Burros Area

Fontugne et al. (1999) also addressed the problem of the local impact of El Niño during the Holocene. Their study was performed in the framework of another archaeological project centered on Quebrada Los Burros, an early Holocene site located some 40 km south of Tacahuay (see Fig. 1B) (Lavallée et al. 1999). According to Fontugne et al. (1999), two major debris-flow deposits (*huaycos*) were formed in Quebrada Los Burros: the oldest one occurred around 8980 cal. B.P. (between QLB2: 8160 ± 70 B.P. and QLB3: 8040 ± 105 B.P., conventional ages), and the youngest one was dated to slightly after 3380 cal. B.P. (see Table 3). Between these two units, ten layers of organic matter and pseudo-peat accumulations were interstratified (Fig. 8). These layers were interpreted by Fontugne et al. (1999) as representing

TABLE 3. Available radiochronological data on latest Pleistocene and Holocene debris-flow and sheet flood deposits in the southern Peru coastal region. Some of these debris flows may be related to El Niño meteorologic conditions, at least during the second half of the Holocene.

Locality/unit	Reference, author	Nature of dated sample and stratigraphic relationships	Lab. No.	Conventional ^{14}C age (^{13}C corrected) ($\pm 1\sigma$) B.P.	Calibrated (calib 3.0) mean age cal. B.P.	Calibrated age range ($\pm 2\sigma$) cal. B.P.	Approximate (or maximum) age of debris flows
Qda. Los Burros, youngest debris flow	Fontugne et al. 1999 (Table 2)	Organic layer underlying a debris-flow deposit	GIF 10641	3220 ± 50	3378	3476–3262	Major event younger than ca. 3380 cal. B.P.
Punta El Ahogado, third youngest debris flow	This work, Fig. 9	Charcoal fragments underlying the third youngest debris-flow deposit preserved in the area	Paris 1769 Paris 1768 Paris 1789	3515 ± 40 3530 ± 60 3660 ± 40	3764 3780 3946	3884–3650 3974–3637 4087–3852	Three major events posterior to ca. 3760 cal. B.P.
Qda. Tacahuay, unit K1 (= T6)	Keefer et al. 1998 (Table 1)	Bulk humic sediment of a major debris-flow deposit	Beta 108536	4550 ± 60	5290	5540–4995	Major event ca. 5290 cal. B.P.
Punta El Ahogado, fourth youngest debris flow	This work, Fig. 9	Charcoal fragments underlying the fourth youngest debris-flow deposit of the area	Paris 1776 Paris 1906	6785 ± 60 6065 ± 70	7573 6854	7673–7477 7177–6730	Major event younger than ca. 6850 cal. B.P. (and older than 3760 cal. B.P.)
Qda. Tacahuay, unit K2	Keefer et al. 1998 (Table 1)	Roots within a minor debris-flow deposit	Beta 108861	7920 ± 80	8655	8975–8485	Minor event ca. 8660 cal. B.P.
Qda. Tacahuay, minor alluvial unit	This work (not shown)	Charcoal fragments associated with a minor alluvial deposit post-T4 and pre-T5	Paris 1924	7970 ± 130	8878	9258–8434	
Qda. Los Burros, oldest debris flow	Fontugne et al. 1999 (Table 2)	Two organic layers (QLB2 and QLB3) bracketing a major debris-flow deposit	GIV 10633 GIF 10634	8160 ± 70 8040 ± 105	8991 8950	9358–8678 9201–8511	Major event ca. 8970 cal. B.P.
Playa Muerta (km 737, Panama Hwy)	Ortlieb, unpublished	Charcoal fragments underlying 4 debris-flow deposits	Bondy Paris/Bondy	8186 ± 150 8055 ± 160	9130 9006	9373–8957 9467–8459	Four major events posterior to ca. 9000 cal. B.P.
Qda. Tacahuay, unit K3	Keefer et al. (Table 1)	Roots within a minor debris-flow deposit	Beta 110330	8430 ± 60	9435	9490–9350	Minor event ca. 9440 cal. B.P.

TABLE 3. *Continued.*

Locality/unit	Reference, author	Nature of dated sample and stratigraphic relationships	Lab. No.	Conventional ^{14}C age (^{13}C corrected) ($\pm 1\sigma$) B.P.	Calibrated (calib 3.0) mean age cal. B.P.	Calibrated age range ($\pm 2\sigma$) cal. B.P.	Approximate (or maximum) age of debris flows
Qda. Tacahuay, unit K4	Keefer et al. 1998 (Table 1)	Charcoal fragments and terrestrial gastropods within a sheet flood deposit	Beta 108858 Beta 108859	9550 ± 90 9630 ± 60	10,560 10,895	10,960–10,355 10,970–10,520	Sheet flood unit ca. 10,560 cal. B.P. between two minor debris flows
Qda. Tacahuay, alluvial unit T4	This work, Fig. 7	Charcoal fragments reworked in an aeolian/water-laid deposit between major debris-flow deposits T3 and T5	Paris 1810	9695 ± 80	10,924	10,997–10,477	Sheet flood unit ca. 10,920 cal. B.P. between debris-flow event T3 and T5
Qda. Tacahuay, alluvial unit T2	This work, Fig. 7	Charcoal fragments (reworked from unit K8) in an aeolian/water-laid deposit, below unit T3, and above the coarse alluvial deposit T1	Paris 1866	10,555 ± 160	12,481	12,818–11,988	Major sheet flood unit T3 bracketed between ca. 10,920 B.P. (T4) and ca. 12,480 cal. B.P.
Qda. Tacahuay, alluvial unit K7	Keefer et al. 1998 (Table 1)	Charcoal fragments in the aeolian/water-laid unit 8 that underlies a major debris-flow deposit (unit 7)	Beta 108860 Beta 108692 Beta 95869	10,530 ± 140 10,750 ± 80 10,770 ± 150	12,490 12,670 12,730	12,790–12,070 12,860–12,460 13,030–12,390	Major event posterior to ca. 12,490 cal. B.P.

more humid spells, with a typical duration of less than 200 years. Such episodes of "increased soil moisture" would have been linked to reinforcements of winter fogs and enhancements of the coastal upwelling strength. Fontugne et al. thus infer that no El Niño would have occurred between 8970 and 3380 cal. B.P.

It must be noted that after 3380 cal. B.P., no other debris-flow deposit was recorded in Los Burros valley.

In this case, as at Tacahuay, the previous authors suggest that debris-flow activity is typical of El Niño conditions, to the point that lack of a debris-flow deposit would imply that no El Niño event occurred. Again, we disagree with this interpretation.

Quebrada Los Burros is a small drainage system surrounded by bare bedrock, particularly in the lower part of the valley. There is scarce superficial soil material susceptible to be reworked by runoff during violent rainfalls. Therefore, we consider that the lack of debris-flow deposit during a given time period should not be interpreted as an indication of absence of intense rainfall. This view is supported by the fact that a strong local rainfall in mid-September 1997 (see Table 1), during an El Niño year, did not generate a characteristic deposit in Quebrada Los Burros, although it produced a debris-flow event less than 2 km to the south, in the small Quebrada El Cañon.

The formation of two debris-flow deposits in Quebrada Los Burros reflected the occurrence of strong rainfalls in the valley, but it still remains to establish that the rainfalls were related to El Niño conditions. The organic-rich layers interstratified between the two debris-flow units indicate that humid conditions persisted for some time in the valley, but these conditions might have been related to a natural (or possibly man-made) dam downstream, in the valley. Such a feature, which can be inferred from the remnants of tuffa and carbonate concretions stuck to the bedrock, may have maintained an artificially high base level within a portion of the valley. Hence, the existence of pseudo-peat deposits in the center of the thalweg may not be directly linked to paleoclimatologic factors.

The sedimentary histories of Quebrada Tacahuay and Quebrada Los Burros show little correspondence. The oldest debris-flow unit of the latter seems to have been almost contemporaneous with the K2 unit of the former (see Table 2).

In Quebrada El Cañon, immediately to the south of Quebrada Los Burros (see Fig. 1B), a complex sedimentary sequence is found that begins with a thick series of coarse alluvial deposits and resembles the Pleistocene part of the Tacahuay sequence (Fig. 8). In Quebrada El Cañon at least a dozen superposed alluvial units of comparable thickness (about 20 cm each) suggest a vigorous alluvial activity of this river, comparable to that of Quebrada Tacahuay. No radiocarbon date has yet been obtained for this series, but the alluvial sequence can be assigned to the Pleistocene because it underlies a major unit of aeolian sand containing human bones dated to 9830 ± 140 B.P. (uncalibrated) (Fontugne and Lavallée, pers. comm., 1999). It is interesting to note that a similar phase of aeolian sand deposition (involving enhanced wind activity) also occurred near the Pleistocene–Holocene transition in the Antofagasta area, 700 km to the south (Llagostera 1979; Vargas 1996; Vargas and Ortlieb 1998).

The informal name of "El Cañon" was given to this *quebrada* because of a deep incision cut into the >50-m-thick sand dune that was built up along the coastline at that time, and which obstructed the mouth of the river. The "cañon" is thus the result of the erosive action of the strongest floods that occurred in the Holocene. The last time that a flood flowed through the cañon was during the 1997–1998 El Niño event.

El Ahogado Sequence

The El Ahogado sequence of debris-flow deposits, which is located halfway between Quebrada Tacahuay and Quebrada Los Burros, was revisited recently (after a preliminary study in 1990). This sequence, observed in a roadcut (Fig. 9), lies on an interfluve between two small *quebradas* at the foot of the 600-m-high coastal range. It consists of a succession of at least 15 debris-flow units. These units, which are 10 to 30 cm thick, can be described as mud flows that incorporate unsorted material from upslope floating in a silty matrix. The reworked clasts are angular to subrounded, ranging in size from a few millimeters to 50 cm in diameter. The sedimentologic characteristics of the deposits clearly indicate that they resulted from mass flow of limited energy that reworked superficial clasts from the alluvial fans accumulated at the foot of the nearby range. They were formed

Figure 9. Late Pleistocene–Holocene debris-flow sequence at Punta El Ahogado, southern Peru. Anthropic charcoals interstratified between debris-flow units provide maximum and minimum ages of major rainfall episodes. The third and fourth youngest debris flows are thus dated as younger than 3760 and 7570 cal. B.P., respectively.

during strong rainfall episodes that struck the coastal region proper, which, in the area, extends only some 3 or 4 km between the range itself and the coastline.

A particularity of this locality is that a few debris-flow units overlie remnants of anthropic activity that can provide radiocarbon dates, and thus the maximum ages of the respective geologic deposits. The third youngest debris-flow unit overlies a layer with abundant marine shells, bird remains, terrestrial mollusks, rope fragments, and charcoal. Three charcoal fragments from this horizon yielded calibrated ages of ca. 3764, 3780, and 3946 cal. B.P. (Table 3). We can therefore infer that the deposit was formed sometime after 3760 cal. B.P. Similarly, the fourth youngest unit overlies a relatively thin, sandy layer that includes a few anthropic remains and many bird remains; charcoal fragments from this horizon yielded a date of 7573 cal. B.P. (Table 3). The maximum age of this penultimate debris-flow deposit can thus be estimated to be around 7570 cal. B.P.

This last finding suggests that at least one other debris-flow episode occurred between the two events dated at Quebrada Los Burros (3380 and 8970 cal. B.P.; Table 3). The ^{14}C date obtained on the youngest anthropic layer does not preclude that the youngest debris flow of Punta El Ahogado (<3760 cal. B.P.) was contemporaneous with the youngest one identified at Quebrada Los Burros (ca. 3380 cal. B.P.). No geochronological data are available from the older debris flows in the El Ahogado sequence.

One other observation, made in a comparable sequence located 600 km to the north of this locality, provides useful information. In a roadcut located at km 737 of the Panamerican Highway, 40 km north of Ocoña, at Playa Muerta (see Fig. 1A), anthropic remains with charcoal fragments dated to 9130 and 9006 cal. B.P. (Table 3) were found below the fourth youngest debris-flow units (Fig. 10). Because of the similarity of the geomorphic situation of the El Ahogado and Playa Muerta debris-flow sequences, we surmise that the two last-formed units in each locality were coeval. The oldest debris-flow units observed at El Ahogado are probably of Pleistocene age.

Because of its morphologic location, on an interfluve, the El Ahogado sequence cannot provide a record of latest Holocene debris-flow activity. The small *quebrada* located immediately to the south of the locality attracted most

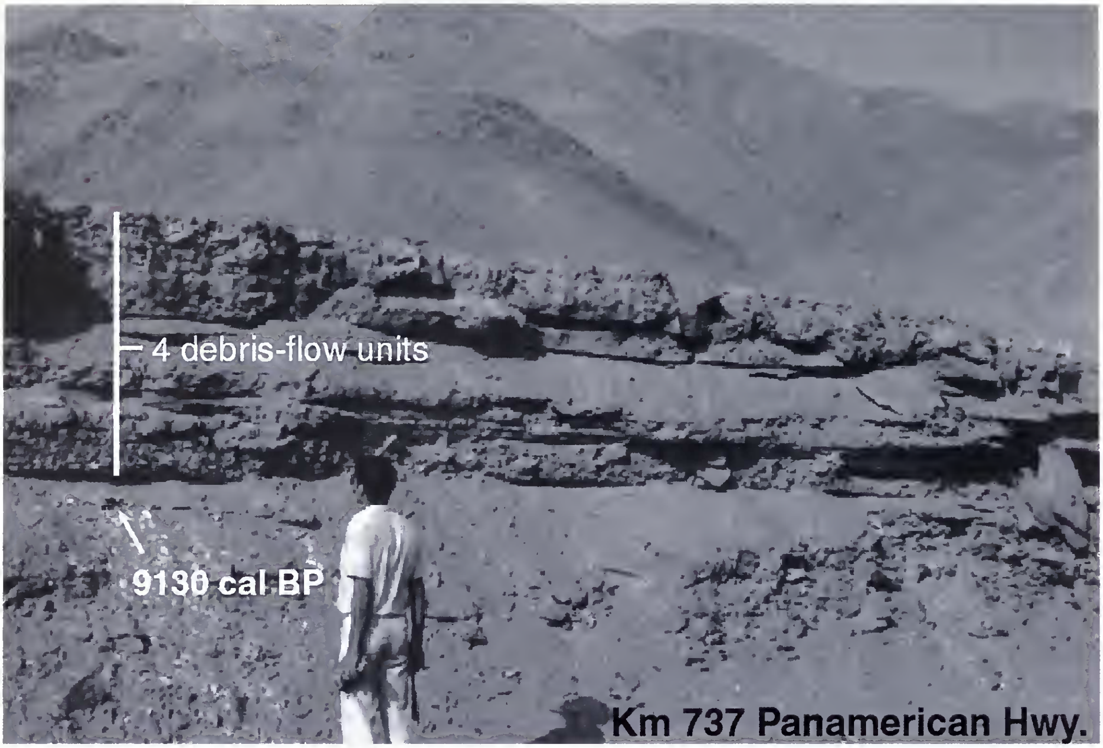

Figure 10. Alluvial sequence of debris-flow deposits at Playa Muerta, southern Peru.

of the debris-flow sediments in the course of the last few millennia.

Regional Correlation of Debris-Flow Remnants

The geochronological data from the four localities—Quebrada Los Burros, Quebrada Tacahuay, Punta El Ahogado, and Playa Muerta—in the southern Peru coastal region suggest that some of the alluvial and debris-flow units may be contemporaneous. Table 4 recapitulates the available data and shows a tentative lateral correlation between the four sequences.

The latest Holocene debris-flow episode observed in Quebrada Los Burros and the third youngest unit at El Ahogado are younger than 3380 cal. B.P. The previous dated event, younger than 5290 cal. B.P., was identified in Quebrada Tacahuay, and may have been preserved at El Ahogado as well. An older event, apparently of strong intensity, might be represented in three localities (Playa Muerta, Tacahuay, and El Ahogado) and can be dated to ca. 8660 cal. B.P. The previous ones were all dated in the Quebrada Tacahuay locality and would have occurred around 9440, before 10,560, before 10,920, at some time between 10,920 and 12,490, and before 12,490 cal. B.P. The localities of Tacahuay, El Ahogado, and El Cañon recorded a series of at least 15 alluvial events before 12,500 cal. B.P.

Discussion

Debris-Flow Significance in Northern Chile and Southern Peru

The extreme aridity of the coastal area of southern Peru favored the formation and subsequent preservation of debris-flow deposits. The narrow coastal plain at the foot of several high rocky mountain ranges, the general lack of soil cover, the abundance of hill-slope material available for transport, and the episodic character of extremely rare rainfall events all contributed to debris-flow activity in this region. Sequences of piled-up debris-flow deposits in areas at the foot of steep alluvial fans or near small *quebradas* are a particularity of the coastal region of southern Peru and northern Chile. Thick sequences of such deposits were studied in the Antofagasta area (23°S), in northern Chile (Vargas 1996; Vargas and Ortlieb 1998). It was shown there that the hydrologic and meteorologic conditions allowing debris-flow activity were set up during the middle Holocene (around 5600 cal. B.P.) and that no debris-flow deposition seems to have occurred in the early Holocene (Vargas et al. 2000; Vargas 2002). Available information on late Pleistocene sedimentary deposits in the Antofagasta region suggests that moderate and possibly regular rains, unable to provoke debris-flow deposits (like those produced under present-day conditions), fell during the Late Glacial Maximum (Vargas 1996; Vargas and Ortlieb 1998). The Pleistocene–Holocene transition was marked in the bay of Antofagasta by the accumulation of an aeolian sand sheet that shows strong wind activity.

Along the southernmost coast of Peru, the geologic record of the late Quaternary suggests a different story than the paleohydrologic reconstruction proposed for the Antofagasta region. We saw that in southern Peru, debris-flow units were formed in the late Pleistocene, the Pleistocene–Holocene transition, and the early Holocene. The record of debris-flow activity during the second half of the Holocene is limited, in contrast to the existence of relatively thick sequences of debris-flow units found in some localities of the Antofagasta area. These differences are interesting and lead us to propose new interpretations regarding the mechanisms involved in the formation of debris-flow deposits and their causal relationship with ENSO conditions in both regions.

In the coastal area of northern Chile, the occurrences of strong rainfall events, able to produce debris-flow activity, are clearly linked to a combination of ENSO conditions and additional favorable circumstances (Garreaud and Rutlland 1996; Vargas et al. 2000). In fact, all of the rainy events with a minimum amount of 20 mm of rainfall that were recorded in the twentieth century in Antofagasta area occurred during El Niño years, while winter precipitation excesses were recorded in central Chile. However, this relationship is conditioned by various other factors that control a northward shift of frontal systems and the spatial distribution of convective activity. During some El Niño years (even of strong intensity), it does not rain in northern Chile.

In southern Peru, we showed that, at least at present, the relationship is much weaker between strong rainfall episodes and ENSO conditions. First, a distinction must be made between the coastal region and the area close to the cordillera. El Niño events are generally characterized by drought in the Altiplano and the Andean areas, while rainy episodes may or may not occur near the coast. As in northern Chile, the convective character of the rains may explain the apparently erratic location of the debris-flow activity, when it is observed. By examining both the instrumental record and historical documentary data, we found that El Niño years are not characterized by precipitation excess (even in the coastal area). This is one difference from the situation observed in northern Chile. Another difference is that heavy rainfall episodes in coastal southern Peru may occur in different seasons. This observation suggests that different regional mechanisms may be involved, some of them possibly unrelated to ENSO conditions. However, it does appear that most debris-flow episodes in southern Peru over the past two centuries occurred during El Niño events.

Before we address the question of the relationship between late Pleistocene and early Holocene debris-flow activity and ENSO conditions, it may be useful to discuss how the geochronological framework for these kinds of deposits was determined.

Dating Debris-Flow Activity

The scarcity of organic matter, plant remains, or material that can be dated within the debris-flow units generally hampers their direct age determination. In only a few cases has it been observed that some mud flow overlaid or reworked charcoal remains and other remnants of human activity (shells, bones). In these cases, the radiocarbon age of the dated material provided a maximum age for the debris-flow activity. In this study, we mentioned only geochronological data obtained on terrestrial material (plants, charcoal, and organic matter) and avoided data based on marine shells or bones of marine mammals. Large uncertainties about the reservoir effects, which may have varied over time in a region subject to various upwelling phenomena (Taylor

TABLE 4. Regional compilation of dated debris-flow and sheet flood events during the latest Pleistocene and first half of the Holocene in southern Peru (see geochronological and morphosedimentary data in Table 3).

Debris-flow event	Alluvial flood event	Maximum (cal.) age B.P.	Playa Muerta (km 737)	Qda. Tacahuay (cal. B.P.)	El Ahogado (cal. B.P.)	Qda. Los Burros (cal. B.P.)
Minor			(undated)	—	(undated)	—
Major			(undated)	—	(undated)	—
Major		≤3380	(undated)	—	≤3760	≤3380
Major		≤5290	(undated)	≤5290 (K1/T6)	≤6850	—
Minor		ca. 8660	<9000	ca. 8660 (K2)		ca. 8970
Minor		ca. 9440		ca. 9440 (K3)		
	Sheet flood	≤10,560		≤10,560 (K4c1)		
	Sheet flood	≤10,920		≤10,920 (T3) (=K4c2?)		
Major		?	Several debris-flow events (prior to 9130 ca. B.P.	Undated (K6)	At least 18 debris-flow events prior to 6850 ca. B.P.	At least 15 pre-Holocene alluvial flood events in Qda. El Canyon (3 km S of Qda. Los Burros)
Major		≤12,490		≤12,490 (K7)		
>8 major events	Sheet flood	>12,730		8 debris-flow and 2 sheet flood events		
	Sheet flood	<38,200 (TL date)				

and Berger 1967; Stuiver and Brazunias 1993; Southon et al. 1995), weigh upon radiocarbon results obtained on carbonates of marine origin. As Kennett et al. (2002) showed in a study based on a comparison of marine and terrestrial material from the Ilo region, it is not yet possible to determine whether the reservoir effect varied significantly since the late Pleistocene in this region. The strong aridity so drastically limited the availability of fuel wood that the charcoal remains of archaeological sites may predate by several centuries the time of their ignition, thus impeding any calibration study between shells and charcoals.

The radiocarbon ages measured on charcoal remains underlying debris-flow deposit are necessarily older than the rainfall episode that provoked the flow. But since the wood used for fire may have been burned several centuries after the death of the tree, the apparent date of the charcoal may be significantly older than measured. These uncertainties must be kept in mind in the proposed comparison between maximum ages of the debris-flow activity in the different studied localities (Tables 3 and 4). However, in spite of these unavoidable sources of unaccuracy, the general chronological framework proposed in Table 4 seems acceptable.

Some of the dates measured on organic material (not charcoal) or roots within sedimentary units of the sequences at Quebrada Tacahuay and Los Burros by earlier authors may be more reliable because their contemporaneity with the deposits is better assessed. Two of this kind of radiocarbon result obtained in each *quebrada* (ca. 8660 and ca. 8970 cal. B.P.) compare reasonably well with the result obtained on the charcoal remains at a third locality (Playa Muerta, <9000 cal. B.P.) (Table 4). This observation brings some confidence to the lateral correlation proposed here between the debris-flow remnants across the region.

The stratigraphic disposition of the debris-flow units studied here, combined with the available geochronological data, thus indicate that a few episodes of strong rainfall occurred before and immediately after the Pleistocene–Holocene boundary. It is inferred that violent rainfalls probably characterized this transition period.

Because of the entrenchment of the hydrographic network starting in the middle Holocene, it is difficult to compare the frequency of occurrence of debris-flow activity throughout the Holocene. Once *quebradas* were subjected to vertical erosion, debris-flow deposits were less likely to be preserved on the interfluves, nor could they be recorded within the valleys. As a result, the limited number of late Holocene debris-flow units may be underestimated. Even with this restriction in mind, it seems clear that the debris-flow activity did not increase during the Holocene—quite the contrary. In the localities visited in southern Peru, only one (or two) debris-flow deposits formed in the last thousand years was preserved, in sharp contrast to the tens of units recorded in Antofagasta Bay. The scarcity of recent debris-flow activity in the study area of southern Peru does not suggest a close relationship between ENSO conditions (known to have occurred with high frequency in the last few centuries) and the occurrence of strong rainfall events.

Evidence for El Niño Conditions in the Latest Pleistocene–Early Holocene

The occurrence of El Niño events and their characteristics (frequency, intensity) during the Early Holocene and at the end of the late Pleistocene is a much debated question (DeVries et al. 1997; Markgraf 1998; Sandweiss et al. 1999; Rodbell et al. 1999; Andrus et al. 2002; Béarez et al. 2003). Keefer et al. (1998, 2001) developed the hypothesis that the presence of debris-flow deposits along the coast of southern Peru constituted evidence for El Niño conditions since before the Late Glacial Maximum up to the present. On the other hand, Fontugne et al. (1999) argued that the lack of debris-flow units between 8970 and 3380 cal. B.P. in Quebrada Los Burros could be interpreted as evidence for the lack of El Niño conditions between these two dates.

In the case of Quebrada Los Burros, it can be objected that lack of a debris-flow record may be due to local geomorphic or hydrologic conditions and does not constitute a strong argument against the occurrence of El Niño events. Anyway, debris-flow units from nearby localities (El Ahogado and Quebrada Tacahuay) provide evidence for the occurrence of local strong rainfall events in the middle Holocene and later.

In Quebrada Tacahuay, debris-flow units and alluvial sediments interstratified in a thick sedimentary sequence that encompasses the late Pleistocene and the first half of the Holocene suggest that the hydrologic conditions were quite different than at present. A thick alluvial sequence observed in Quebrada El Cañon (Fig. 8) supports the hypothesis that a high runoff existed at the end of the Pleistocene in the region. A much wetter climate, with respect to the present-day situation, may thus have characterized the area between at least 13,000 cal. B.P. (or the Late Glacial Maximum?) and ca. 9000 cal. B.P. If, as we suspect, this was true, then there is no reason to extrapolate the current (weak) relationship between ENSO and strong rainfalls. Local, relatively strong rainfalls may completely explain episodic debris-flow activity and the coarse alluvial deposits in several localities of coastal southern Peru.

Hence, we conclude that in coastal southern Peru, debris-flow activity is not straightforwardly related to ENSO conditions, even if instrumental data for the last decades and documentary historic data tend to suggest that some weak relationship may have existed recently. For more remote periods, during the postglacial late Pleistocene and early Holocene, the climatologic regime was quite different than at present. Until better knowledge of this regime is obtained, we believe it is misleading to infer a causal relationship between debris flow and ENSO in southern Peru for periods prior to the middle Pleistocene.

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Literature Cited

ACEITUNO, P. 1988. On the functioning of the Southern Oscillation in the South American sector: Part 1. Surface climate. Monthly Weather Review, **116**(3): 505–524.

———. 1990. Anomalías climáticas en la región sudamericana durante los extremos de la Oscilación Austral. Revista Geofisica (Mexico), **32:** 65–78.

ALFARO CALDERÓN, C. A. 1936. Reseña histórica de la Provincia de Tarapacá. Iquique, 550 pp.

ALLAN, R., J. LINDESAY, AND D. PARKER. 1996. El Niño Southern Oscillation and Climatic Variability. CSIRO, Collingwood, Australia, 405 pp.

ALMEYDA, E. 1948. Pluviometría de las zonas del desierto y las estepas cálidas de Chile. Editorial Universitaria, Santiago, 162 pp.

ANDRUS, C. F. T., D. E. CROWE, D. H. SANDWEISS, E. J. REITZ, AND C. R. ROMANEK. 2002. Otolith δ ^{18}O record of Mid-Holocene sea surface temperatures in Peru. Science, **295:** 1510–1512.

BASADRE, M. 1884. Riquezas Peruanas. Imprenta de La Tribuna, Lima, 224 pp.

BÉAREZ, P., T. J. DEVRIES, AND L. ORTLIEB. 2003. Comment on "Otolith δ ^{18}O record of Mid-Holocene sea surface temperatures in Peru." Science, **299:** 203A.

BILLINGHURST, G. 1886. Estudio sobre la geografía de Tarapacá. Imprenta El Progreso, Santiago.

BOWMAN, I. 1924. Desert trails of Atacama. American Geographical Society, Special Publication 5, 362 pp.

CARRANZA, L. 1891. Contracorriente maritima observada en Payta y Pacasmayo. Boletín de la Sociedad Geográfica de Lima, **1:** 344–345.

CAVIEDES, C. N. 1981. Rainfall in South America: Seasonal trends and spatial correlations. Erdkunde, **35:** 107–118.

COBO, B. 1653 [1964]. Historia del Nuevo Mundo. *In* F. Mateos, ed., Obras del Padre Bernabe Cobo, vol. 1. Biblioteca de Autores Españoles, Madrid, 439 pp.

COUYOUMDJIAN, R., AND H. LARRAIN. 1975. El plano de la Quebrada de Tarapaca, de don Antonio O'Brien: Su valor geográfico y socio-antropológico. Norte Grande (Universitaria Católica de Chile), **1**(3–4): 329–362.

DESER, C., AND J. M. WALLACE. 1987. El Niño events and their relation to the Southern Oscillation: 1925–86. Journal of Geophysical Research, **92**(C13): 14189–14196.

DEVRIES, T. J. 1987. A review of geological evidence for ancient El Niño activity in Peru. Journal of Geophysical Research, **92**(C13): 14471–14479.

DEVRIES, T. J., L. ORTLIEB, A. DÍAZ, L. WELLS, AND C. HILLAIRE-MARCEL. 1997. Determining the early history of El Niño. Science, **276:** 965–966.

DEVRIES, T. J., AND L. E. WELLS. 1990. Thermally-anomalous Holocene molluscan assemblages from coastal Peru: Evidence for paleogeographic, not climatic change. Palaeogeography, Palaeoclimatology, Palaeoecology, **81:** 11–32.

Diaz, A., and L. Ortlieb. 1993. El fenómeno "El Niño" y los moluscos de la costa peruana. Bulletin de l'Institut Français d'Etudes Andines (Lima), **22**(1): 159–177.

El Comercio. 1899. Sección interior (Mollendo, Moquegua), 17 Febrero 1899; Sección crónica ("Lluvias," Arequipa), 22 Febrero 1899; Sección interior (Moquegua, Arequipa), 24 Febrero 1899; Sección interior (Arequipa), 25 Febrero 1899. *El Comercio,* Lima.

Fontugne, M., P. Usselmann, D. Lavallée, M. Julien, and C. Hallé. 1999. El Niño variability in the coastal desert of southern Peru during the Mid-Holocene. Quaternary Research, **52:** 171–179.

Francou, B., and L. Pizarro. 1985. El Niño y la sequía en los altos Andes centrales: Perú y Bolivia. Bulletin Institut Français d'Etudes Andines, **14**(1–2): 1–18.

Garcia Peña, A., and L. Fernández. 1985. Analisis climático de las regiones de la sierra y selva en períodos que ocurren fenómenos El Niño, pp. 521–550. *In* Proceedings of the Seminario Regional Ciencia, Tecnologia y Agresión Ambiental, El Fenómeno El Niño. CONCYTEC, Lima.

Garreaud, R., and J. Rutllant. 1996. Análisis meteorológico de los aluviones de Antofagasta y Santiago de Chile en el período 1991–1993. Atmósfera, **9:** 251–271.

Gierke Kittsteiner, H. J. 1985. Arica, Tierra de historia, vol. 1. Editorial Universitaria, Santiago, 183 pp.

Guzmán, N., A. Díaz, L. Ortlieb, and M. Clarke. 2001. "TAMAs," occurrencia episódica de moluscos "tropicales" en el Norte de Chile y el fenómeno El Niño, pp. 385–393. *In* J. Tarazona, W. E. Arntz, and E. Castillo de Maruenda, eds., El Niño en América Latina: Impactos Biológicos y Sociales. Consejo Nacional de Ciencia y Tecnología, Lima.

Hamilton, K., and R. R. Garcia. 1986. El Niño/Southern Oscillation events and their associated midlatitude teleconnections, 1531–1841. Bulletin of the American Meteorological Society, **67:** 1354–1361.

Hastenrath, S. L. 1985. Climate and Circulation of the Tropics. Reidel, Dordrecht, 455 pp.

Hocquenghem, A. M., and L. Ortlieb. 1992. Eventos El Niño y lluvias anormales en la costa del Peru: Siglos XVI–XIX. Bulletin de l'Institut Français d'Etudes Andines, **21**(1): 197–278.

Huaman Solis, F., and A. Garcia Peña. 1985. Condiciones meteorológicas en el Perú durante el fenómeno "El Niño" 1982–83, pp. 333–353. *In* Proceedings of the Seminario Regional Ciencia, Tecnologia y Agresión Ambiental, El Fenómeno El Niño. CONCYTEC, Lima.

Keefer, D. K., S. D. deFrance, M. E. Moseley, J. Richardson, D. R. Satterlee, and A. Day-Lewis. 1998. Early maritime economy and El Niño events at Quebrada Tacahuay, Peru. Science, **281:** 1833–1835.

Keefer, D. K., M. E. Moseley, and S. D. deFrance. 2001. Paleoflood and debris-flow deposits in the Ilo Region, far south coast of Peru: A 38,000 year record of severe El Niño events? *In* Paleoclimatology of the Central Andes Workshop, abstract.

Kendrew, W. G. 1961. The Climates of the Continents. Clarendon Press, Oxford, 608 pp.

Kennett, D. J., B. L. Ingram, J. R. Southon, and K. Wise. 2002. Differences in 14C age between stratigraphically associated charcoal and marine shell from the Archaic period site of Kilometer 4, Southern Peru: Old wood or old water? Radiocarbon, **44**(1): 53–58.

Klohn, W. 1972. Hidrografia de las zonas desérticas de Chile. Programa de Naciones Unidas para el Desarrollo, Santiago de Chile, 188 pp.

Labarthe, P. A. 1914. Las avenidas extraordinarias en los rios de la costa. Informes y Memorias de la Sociedad de Ingenieros del Perú, **16**(11–12): 301–329.

Larrain, H. 1974. Análisis de las causas de despoblamiento entre las comunidades indígenas del Norte de Chile, con especial referencia a las hoyas hidrográficas de las quebradas de Aroma y Tarapacá. Norte Grande, **1**(2): 125–154.

Lavallée, D., M. Julien, P. Béarez, P. Usselmann, M. Fontugne, and A. Bolaños. 1999. Pescadores-recolectores arcáicos del extremo-sur peruano. *In* Excavaciones en la Quebrada de los Burros (Tacna, Perú): Primeros resultados. Bulletin Institut Français d'Etudes Andines, in press.

Llagostera, A. 1979. 9700 years of maritime subsistence on the Pacific: An analysis by means of bioindicators in the North of Chile. American Antiquity, **44**(2): 309–323.

Llano y Zapata, J. E. 1748. Observación Diaria Critico-Histórico Meteorológica, Contiene Todo lo Acaecido en Lima Desde Marzo de 1747 Hasta 28 de Octubre del Mismo Año, etc. Manuscript letters, Biblioteca Nacional de Lima, Lima, 50 pp.

Macharé, J., and L. Ortlieb. 1993. Registros del fenómeno El Niño en el Perú. Bulletin de l'Institut Français d'Études Andines, Lima, **22**(1): 35–52.

Markgraf, V. 1998. Past climates of South America, pp. 249–264. *In* J. E. Hobbs, J. A. Lindsay, and H. A. Bridgman, eds., Climates of the Southern Continents: Present, Past and Future. John Wiley and Sons, New York.

Melo, R. 1913. Hidrografía del Perú. Boletín de la Sociedad Geográfica de Lima, **29**(1–2): 141–159.

Minaya, N. A. 1993. El Niño/Oscilación del Sur y las descargas del Rio Camana-Majes. Espacio y Desarrollo, **5:** 53–71.

———. 1994. El Niño/Oscilación del Sur y las precipitaciones en la costa central y sur del Perú. Unpublished report, Pontificia Universidad Católica del Perú, Instituto Geofísico del Perú, Lima, 118 pp.

Murphy, R. C. 1926. Oceanic and climatic phenomena along the west coast of South America during 1925. Geographical Review, **16:** 26–54. [Spanish translation also published in 1926: Fenómenos oceánicos y climatéricos en la costa occidental de

Sur-America durante el año 1925. Boletín de la Sociedad Geográfica de Lima, **63**(2): 87–125.]

Ortlieb, L. 1995. Eventos El Niño y episodios lluviosos en el Desierto de Atacama: El registro de los dos últimos siglos. Bulletin de l'Institut Français d'Etudes Andines, **24**(3): 519–537.

———. 1997. Correlation of historical records of El Niño events between Chile, Peru and Ecuador (Galapagos), pp. 93–94. Proceedings of a conference, Seminario Internacional Consecuencias Climaticas e Hidrologicas del Evento El Niño a Escala Regional y Local: Incidencia en America del Sur. INAMHI and ORSTOM, Memorias técnicas, Quito, November 1997.

———. 1998. Historical reconstructions of ENSO events from documentary sources from Chile, Peru, Brasil, and Mexico: Evidence for variability of the teleconnection regime in the last centuries. Abstracts of a conference, PEP 1: Pole-Equator-Pole Paleoclimate of the Americas, Science Meeting. Merida, Venezuela, March 1998.

———. 1999. La "calibration" des événements ENSO des derniers siècles ("Calibration" studies for ENSO events of the last few centuries). Lettre PIGB-PMRC, April 1999: 29–37 + p. vi.

———. 2000. The documentary historical record of El Niño events in Peru: An update of the Quinn record (sixteenth through nineteenth centuries). *In* H. Diaz and V. Markgraf, eds., El Niño and the Southern Oscillation: Variability, Global and Regional Impacts. Cambridge University Press, Cambridge, U.K. (in press).

Ortlieb, L., T. DeVries, and A. Díaz. 1990. Ocurrencia de *Chione broggi* (Pilsbry & Olsson, 1943) (Pelecypoda) en depósitos litorales cuaternarios del sur del Perú: Implicaciones paleoceanográficas. Boletín de la Sociedad Geológica del Perú, **81:** 127–134.

Ortlieb, L., A. Díaz, and N. Guzmán. 1996. A warm interglacial episode during oxygen isotope stage 11 in Northern Chile. Quaternary Science Reviews, **15:** 857–871.

Ortlieb, L., E. Fuentes, N. Guzmán, and A. Llagostera. 1997. Paleotemperatura del mar en la Bahia de Antofagasta, durante la transicion Pleistoceno-Holoceno: Resultados preliminares de analisis isotópicos seriados en conchas de *Concholepas concholepas,* pp. 366–370. Abstracts, VIII Congreso Geológico Chileno, Antofagasta, 1997.

Ortlieb, L., and L. Macharé. 1993. Former El Niño events: Records from western South America. Global & Planetary Changes, **7:** 181–202.

Ortlieb, L., G. Vargas, and A.-M. Hocquenghem. 2002. ENSO reconstruction based on documentary data from Ecuador, Peru and Chile. PAGES Newsletter, **10**(3): 14–17.

Perrier, C., C. Hillaire-Marcel, and L. Ortlieb. 1994. Paléogéographie littorale et enregistrement isotopique (^{13}C, ^{18}O) d'événements de type El Niño par les mollusques holocènes et récents du nord-ouest péruvien. Géographie Physique et Quaternaire, **48**(1): 23–38.

Petersen, G. 1935. Estudios climatológicos del Nordeste peruano. Boletín de la Sociedad Geológica del Perú, **7**(2): 1–141.

Philander, G. S. 1991. El Niño, La Niña and the Southern Oscillation. Academic Press, San Diego, California.

Quinn, W. H. 1993. The large-scale ENSO event, the El Niño, and other important features. Bulletin de l'Institut Français d'Etudes Andines, **22**(1): 13–34.

Quinn, W. H., and V. T. Neal. 1983. Long-term variations in the Southern Oscillation, El Niño, and Chilean subtropical rainfall. Fishery Bulletin, **81**(2): 363–374.

———. 1992. The historical record of El Niño events, pp. 623–648. *In* R. S. Bradley and P. D. Jones, eds., Climate Since A.D. 1500. Routledge, London.

Quinn, W. H., V. T. Neal, and S. Antúnez de Mayolo. 1987. El Niño occurrences over the past four and a half centuries. Journal of Geophysical Research, **92**(C13): 14449–14461.

Rodbell, D. T., G. O. Seltzer, D. M. Anderson, M. B. Abbott, D. B. Enfield, and J. H. Newman. 1999. An ~15000-year record of El Niño-driven alluviation in Southwestern Ecuador. Science, **283:** 516–520.

Rollins, H. B., J. B. Richardson, and D. H. Sandweiss. 1986. The birth of El Niño: Geoarcheological evidence and implications. Geoarcheology, **1**(1): 3–15.

Rome-Gaspaldy, S., and J. Ronchail. 1998. La pluviométrie au Pérou pendant les phases ENSO et LNSO. Bulletin de l'Institut Français d'Etudes Andines, **27**(3): 675–685.

Ropelewski, C. C., and M. S. Halpert. 1987. Global and regional scale precipitation patterns associated with El Niño/Southern Oscillation. Monthly Weather Review, **115:** 1606–1626.

Rossel, F. 1997. Influence du Niño sur les régimes pluviométriques de l'Equateur. Doctoral diss., Université Montpellier II, France, 289 pp.

Rossel, F., R. Mejía, G. Ontaneda, R. Pomposa, J. Roura, P. Le Goulven, E. Cadier, and R. Calvez. 1998. Régionalisation de l'influence du El Niño sur les précipitations de l'Equateur. Bulletin de l'Institut Français d'Etudes Andines, **27**(3): 643–654.

Rutllant, J., and H. Fuenzalida. 1991. Synoptic aspects of the central Chile rainfall variability associated with the Southern Oscillation. International Journal of Climatology, **11:** 63–76.

Sandweiss, D. H. 1986. The beach ridges at Santa, Peru: El Niño, uplift and prehistory. Geoarcheology, **1**(1): 17–28.

Sandweiss, D. H., K. A. Maasch, and D. G. Anderson. 1999. Transitions in the Mid-Holocene. Science, **283:** 499–500.

Sandweiss, D. H., J. B. Richardson, E. J. Reitz, H. B. Rollins, and K. A. Maasch. 1996. Geoarcheological evidence from Peru for a 5,000 years BP onset of El Niño. Science, **273:** 1531–1533.

Sandweiss, D. H., H. B. Rollins, and J. B. Richardson. 1983. Landscape alteration and prehistoric human occupation on the north coast of Peru. Annals of the Carnegie Museum, **52**(2): 277–298.

Southon, J. R., A. Rodman, and D. True. 1995. A comparison of marine and terrestrial radiocarbon ages from Northern Chile. Radiocarbon, **37**(2): 389–393.

Stuiver, M., and T. F. Brazunias. 1993. Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. Radiocarbon, **35**(1): 137–189.

Suardo, J. A. 1629–39 [1936]. Diario de Lima de Juan Antonio Suardo, vol. 2. Biblioteca Histórica Peruana, Universidad Católica del Perú, Lima, 201 pp.

Taylor, R. E., and R. Berger. 1967. Radiocarbon content of marine shells from the Pacific coast of central and south America. Science, **158:** 1180–1182.

Thompson, L. G., E. Mosley-Thompson, and B. Morales-Arnao. 1984. El Niño Southern Oscillation events recorded in the stratigraphy of the tropical Quelccaya ice cap, Peru. Science, **226:** 50–53.

Urrutía de Hazbún, R., and C. Lanza Lazcano. 1993. Catástrofes en Chile 1541–1992. Editorial la Noria, Santiago, Chile, 440 pp.

Vargas, G. 1996. Evidencias de cambios climáticos ocurridos durante el Cuaternario en la zona de Antofagasta, II Región. Master's thesis, Departamento de Geología, Universidad de Chile, Santiago, 174 pp.

———. 2002. Interactions océan-atmosphère au cours des derniers siècles sur la côte du Désert d'Atacama: Analyse multi-proxies des sédiments laminés de la Baie de Mejillones (23 S). Doctoral diss., Universite de Bordeaux 1, Bordeaux, France, 270 pp.

Vargas, G., and L. Ortlieb. 1998. Patrones de variaciones climáticas durante el Cuaternario tardío en la costa de la Región de Antofagasta, Chile. Bulletin de l'Institut Français d'Etudes Andines, **27**(3): 385–394.

Vargas, G., L. Ortlieb, and J. Rutllant. 2000. Aluviones históricos en Antofagasta y su relación con eventos El Niño/Oscilación del Sur. Revista Geológica de Chile, **27**(2): 155–174.

Wells, L. E. 1988. Holocene Fluvial and Shoreline History as a Function of Human and Geologic Factors in Arid Northern Peru. Doctoral diss., Stanford University, Stanford, California, 381 pp.

Whetton, P., R. Allan, and L. Rutherfurd. 1996. Historical ENSO teleconnections in the eastern hemisphere: A comparison with latest El Niño series of Quinn. Climatic Change, **32:** 103–109.

Whetton, P., and L. Rutherfurd. 1994. Historical ENSO teleconnections in the eastern hemisphere. Climatic Change, **28:** 221–253.

Wormald Cruz, A. 1972. Historias olvidadas del Norte Grande. Universidad del Norte, Departamento de Historia y Geografía, Arica, 298 pp.

4

Paleoenvironment at Almejas: Early Exploitation of Estuarine Fauna on the North Coast of Peru

Shelia Pozorski and Thomas Pozorski

The preceramic site of Almejas, with radiocarbon dates averaging about 5000 B.C.,[1] is among the earliest marine-oriented sites in the Casma Valley of Peru. The site consists of a dense shell midden over 1 m deep that is unusual because of the predominance of warm-water mud-flat mollusks among the remains. Along with these mollusks, an abundance of estuarine fishes indicates a very rich estuarine ecosystem close to the site. A single, well-preserved burial was also encountered within the shell midden. The collective data from Almejas provide information about early coastal settlement that is pertinent to critical, much-debated issues regarding the timing of current sea level attainment and the antiquity of the present climatic regime, including periodic El Niño-related events.

The Site of Almejas

Location and Surface Features

A tiny preceramic site located near the abandoned hacienda San Diego was named Almejas, a Spanish word meaning clam, because of the abundant bivalve shells found on the surface (Fig. 1). The site lies along the north side of a granite outcrop against which considerable granitic sand is banked. Almejas is now about 5.5 km from the Pacific Ocean and about 25 m above sea level, but the intervening area is quite low, less than 5 m above sea level (masl), and was once a large shallow estuary (Fig. 1).

In the immediate vicinity of the site are abundant remains of much later Early Intermediate Period and Late Intermediate Period (200 B.C. to A.D. 1470) settlement, including a large cemetery, cane foundations of *quincha* (wattle-and-daub) houses, and rich midden with abundant plant remains. Slightly further north, in a natural basin also formed by low granitic hills, lies the Early Horizon site of San Diego (Pozorski and Pozorski 1987:51–65; Tello 1956:296–298; Thompson 1961:74–75, 241–244, 1964:208).

Excavations at Almejas

Almejas is distinguishable on the surface as an irregular patch of very dense shell about 95 m north-south by 50 m east-west. Excavation of four test pits within the area of dense shell revealed that this shell extends to a depth of 135 cm. A 1-m^2 controlled stratigraphic excavation of the test pit exposed the deepest and best-preserved midden deposit. Portions of the upper levels had been disturbed and contaminated by the activities of later inhabitants. These mixed zones, which occasionally penetrated to a depth of 40 cm, were easily detected, both because of the extremely weathered condition of the early

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[1] The 5000 B.C. date is based on uncalibrated radiocarbon dates. If calibrated dates were used, then the date for the site would be about 5900 B.C. However, for the purposes of this discussion, uncalibrated dates are used because the dates cited here for comparative purposes have been reported in the archaeological literature as uncalibrated dates.

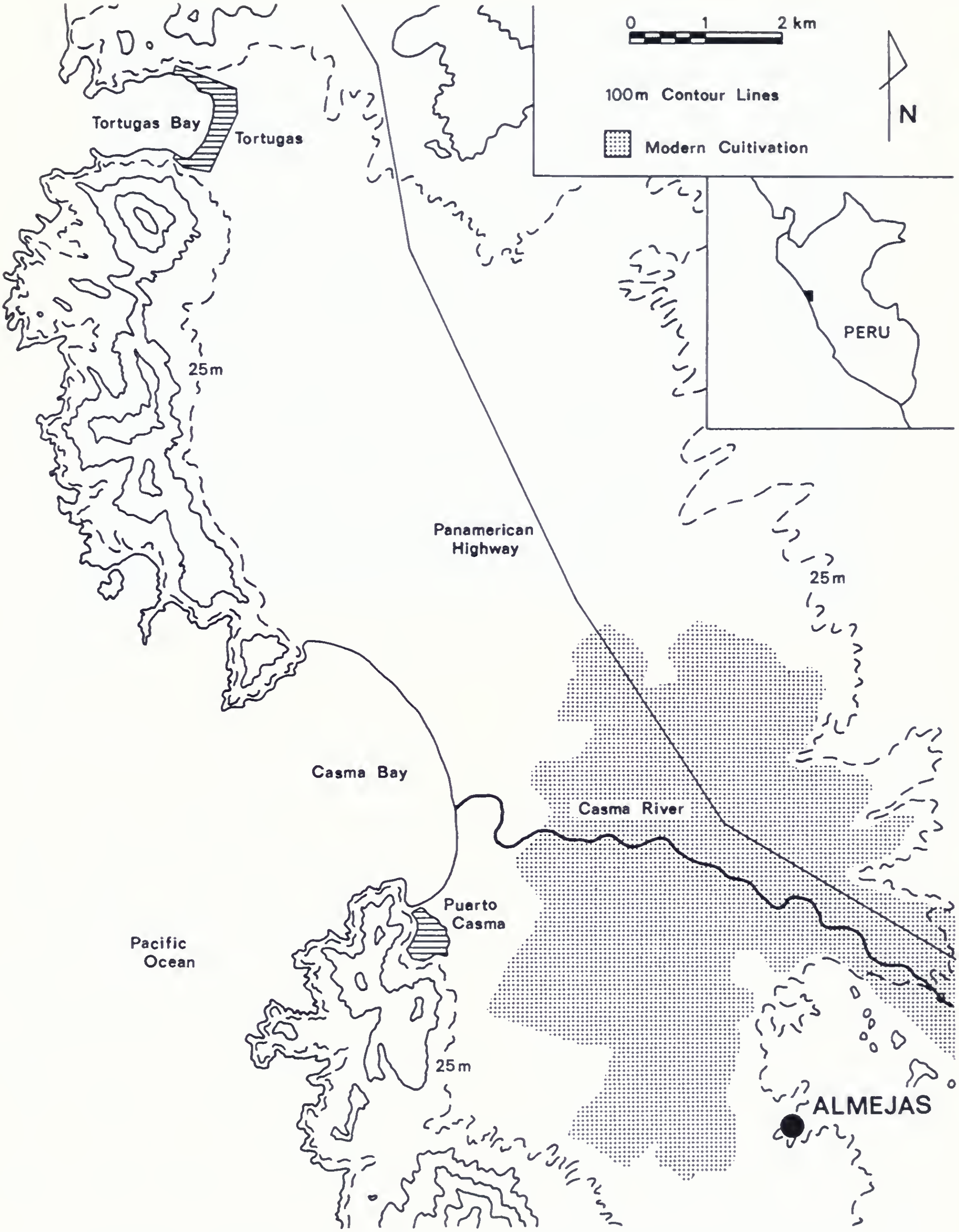

Figure 1. Map of the lower Casma Valley showing the location of the site of Almejas.

Figure 2. View from above showing three large boulders on top of the Almejas burial.

shell and because of the presence of intrusive late elements such as ceramics, camelid dung, and maize. The lower levels, however, were undisturbed and contained predominantly marine shell, fish bone, and wild plant remains. A burial was discovered within these intact lower levels.

As the controlled stratigraphic excavation was carried out, excavation followed the visible stratigraphy. Thick levels were arbitrarily subdivided into artificial levels 25 cm or less in thickness. Initial excavation of each level involved the removal of a 25-cm² column sample of midden that was screened through successively smaller mesh: ¼ in. screen, a no. 10 geological sieve, and a no. 25 geological sieve. The remaining material from the more general excavation of each level was screened through a ¼ in. screen. The plant and animal remains recovered when the column sample was screened through the ¼ in. mesh were included as part of the general excavation material. Remains recovered using the geological sieves were bagged separately according to mesh size. The animal bone recovered using the geological sieves was analyzed separately, but the results have been combined here under the term "column sample." Volume measurements in liters were recorded for all excavation units within the stratigraphic cut.

Burial

A preceramic burial was encountered near the bottom of the stratigraphic excavation at a depth of 100 cm below the modern ground surface (Figs. 2 through 4). The first clue that a burial was present was three large boulders that lay on top of the burial wrapping (Fig. 2). This burial wrapping consisted of a well-preserved covering of parallel *junco* reeds (*Cyperus* sp.) laid lengthwise and closely spaced to cover the body (Fig. 3), but without any evidence of twining or tying.

The body (Fig. 4) was tightly flexed, lying on the right side with the head toward the north. The arms were flexed, bringing both hands into position beneath the chin. Based on examination of the pelvis, the skeleton was determined to be that of a male. Formulae for stature calculations developed by Genoves (1967; reproduced in Bass 1987:29) indicate that the man's stature when alive would have been approxi-

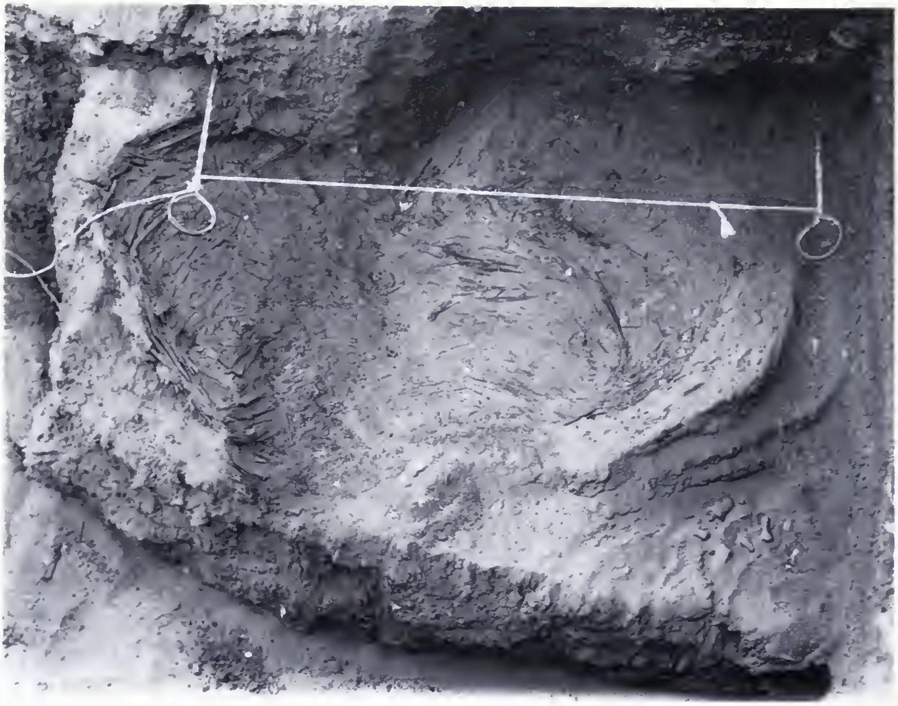

Figure 3. View from above of the Almejas burial after removal of the three large boulders. Well-preserved loose *junco* (*Cyperus* sp.) fibers covered the exterior of the body.

mately 161.5 cm. His age at death is estimated at approximately 35 to 45 years. This age determination is based on complete closure of all epiphyses (Bass 1987:13–19), slight arthritic lipping on the cervical vertebrae (Bass 1987: 19), and tooth wear as measured against the scale developed by Brothwell (1981:72). All four third molars, the lower second premolars, and both lower right incisors were lost well before death; their corresponding sockets are no longer visible. The remaining teeth are very worn, exposing the dentine. Both ears contain bony growths known as auditory exostoses; the condition is particularly severe in the left ear. These commonly result from trauma to the ear canal when the thin skin there is exposed to cold water while an individual is exploiting cold-water resources (Kennedy 1986; Quilter 1989:21; Tattersall 1985:60–64; Wise et al. 1994:217).

A large quartz crystal (Figs. 4 and 5) was discovered near the left hand, where it may have been held. This item is unique in such a context; and, given the frequent inclusion of quartz crystals among power objects on the *mesas* of modern shamans practicing on the Peruvian north coast (Joralemon and Sharon 1993: 20, 32, 54, 68, 80, 95, 107), the quartz crystal from Almejas may also have served prehistorically as a power object for communicating with and influencing the supernatural. This find represents the earliest such evidence of possible shamanistic practices along the entire central Andean coast.

A total of 52 perforated shell discs were also collected from the grave fill between the *junco* wrapping and the center portion of the body (Fig. 5). These were likely strung as beads, possibly once forming a necklace. Most of the shell discs were manufactured from *Trachycardium procerum* and *Argopecten purpuratum* shells, although a few may have been fashioned from the mussel *Mytella guyanensis* and the gastropod *Thais chocolata*. Shell beads and worked or cut shell ornaments have been found in some burials at Late Preceramic sites (Bird and Hyslop 1985:66, 220; Feldman 1980:114, 121; Moseley 1992:116; Quilter 1989:53–74 *passim*; Wendt 1976:34) and earlier preceramic sites (Stothert 1985:627).

Other than the quartz crystal and shell discs associated with the burial, very few artifacts

Figure 4. View from above of the excavated male skeleton at Almejas. The individual was 35 to 45 years old at the time of death and was buried with 52 perforated shell discs, which likely once formed a necklace, and a large quartz crystal, which he held in his left hand.

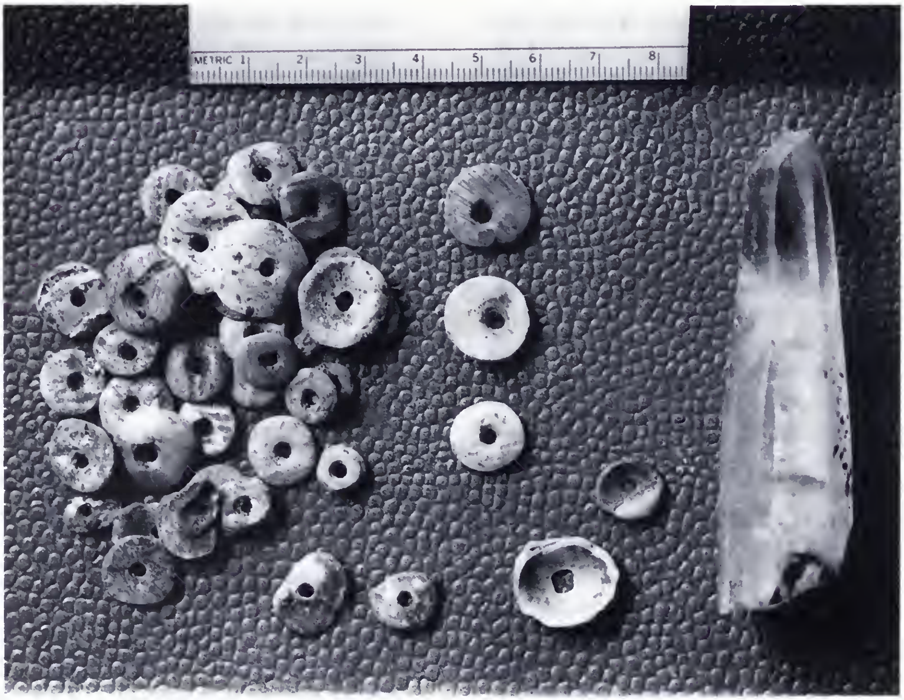

Figure 5. Perforated shell discs and the large quartz crystal found with the Almejas burial.

TABLE 1. Radiocarbon dates from Almejas.

Sample no.	Radiocarbon years* B.C.	B.C. equivalents	Calibrated date†	Material	Context
UGa-4518	7195 ± 75	5245 ± 75	5980 ± 130	Charcoal	Stratigraphic cut, level 4c, 80 cm below surface
UGa-4519	7220 ± 70	5270 ± 70	6000 ± 120	Charcoal	Stratigraphic cut, level 4e, 100 cm below surface
UGa-4539	6875 ± 105	4925 ± 105	5675 ± 180	Junco	From burial fiber wrapping, burial cut into level 4e

* All dates are based on the Libby half-life (5568 ± 30 years) and have no $^{13}C/^{12}C$ corrections.
† Calibrations are based on charts in Stuiver and Becker (1993).

were encountered at Almejas. These additional artifacts include rounded shell discs and perforated pieces of shell that may represent partially shaped perforated shell discs or beads.

The burial at Almejas is one of the earliest preceramic burials that have been found along the central Andean coast. Dating to approximately 5000 B.C., this burial predates all burials associated with the Late Preceramic Period or the Cotton Preceramic Period (3000–1800 B.C.), a time period associated with the use of twined cotton textiles for clothing, burial wrappings, and netting (Bird and Hyslop 1985:64–76; Lanning 1967:61; Moseley 1983:208, 1992:108–109). A few widely scattered coastal sites have yielded burials of comparable age: the earliest burials at La Paloma on the central Peruvian coast (Quilter 1989:11, 163–165), the burials associated with the Late Las Vegas phase at the Las Vegas in southern Ecuador (Stothert 1985: 618–619), and those of the Chinchorro Culture in northern Chile and the far south coast of Peru (Arriaza 1995:127–130). Somewhat earlier burials (6000–8000 B.C.) have been found within the Chinchorro culture sites (Arriaza 1995: 126–127), at Encampment 96 of Paracas Bay (Arriaza 1995:55; Engel 1981:31–32; Quilter 1989:71), at the Paijan culture sites of Quirihuac Shelter in the Moche Valley (Chauchat 1988:49–51; Moseley 1992:87), and in the Cupisnique desert north of the Chicama Valley (Chauchat 1978b:60, 1988:59–63).

The Almejas burial has several traits typical of and other traits not so characteristic of preceramic burials along the central Andean coast. The body itself was buried in its natural state with no attempt at artificial mummification. With the exception of the unique Chinchorro Culture (Arriaza 1995), this was standard treatment for all preceramic burials along the coast. The flexed position of the Almejas body, lying on one side, is typical of many preceramic sites, including those contemporary with, earlier than, and later than the Almejas burial (Bird and Hyslop 1985:64–76; Engel 1981:32–38; Feldman 1980:114–122; Grieder et al. 1988:Table 4; Moseley 1992:116; Pozorski and Pozorski 1979:351–354, 1987:20; Quilter 1989:53; Stothert 1985:625; Wendt 1976:29–30; Wise et al. 1994:215). The presence of large stones on top of the Almejas burial is also a trait shared with burials at several preceramic sites (Bird and Hyslop 1985:66; Pozorski and Pozorski 1979:353, 1987:20; Quilter 1989:83; Stothert 1985:625; Wendt 1976:30). The wrapping of bodies was a widespread practice in preceramic times. In Late Preceramic times, cotton cloth was most frequently used (Bird and Hyslop 1985:64–76; Feldman 1980:114–122; Moseley 1992:116); also common was the use of twined or woven matting (Bird and Hyslop 1985:66–74; Engel 1976:97, 1981:32–38; Feldman 1980: 114–118; Fung Pineda 1988:95; Quilter 1989: 53, 70–82; Wendt 1976:30–31). The use of loose *junco* fibers, *totora* reeds, or other loose plant fiber as a burial wrapping was less common (Bird and Hyslop 1985:74; Pozorski and Pozorski 1987:20; Quilter 1989:87–162).

Subsistence and Environment

Two features of Almejas distinguish the site from other preceramic sites of the central and north coast. First, the radiocarbon dates for the site, averaging about 5000 B.C. (Table 1), are unusually early. Second, the predominant faunal remains argue for a nutrient-rich estuary in the vicinity of the site. The molluscan inventory is dominated by species that disappeared from the Casma area quite early and are now largely

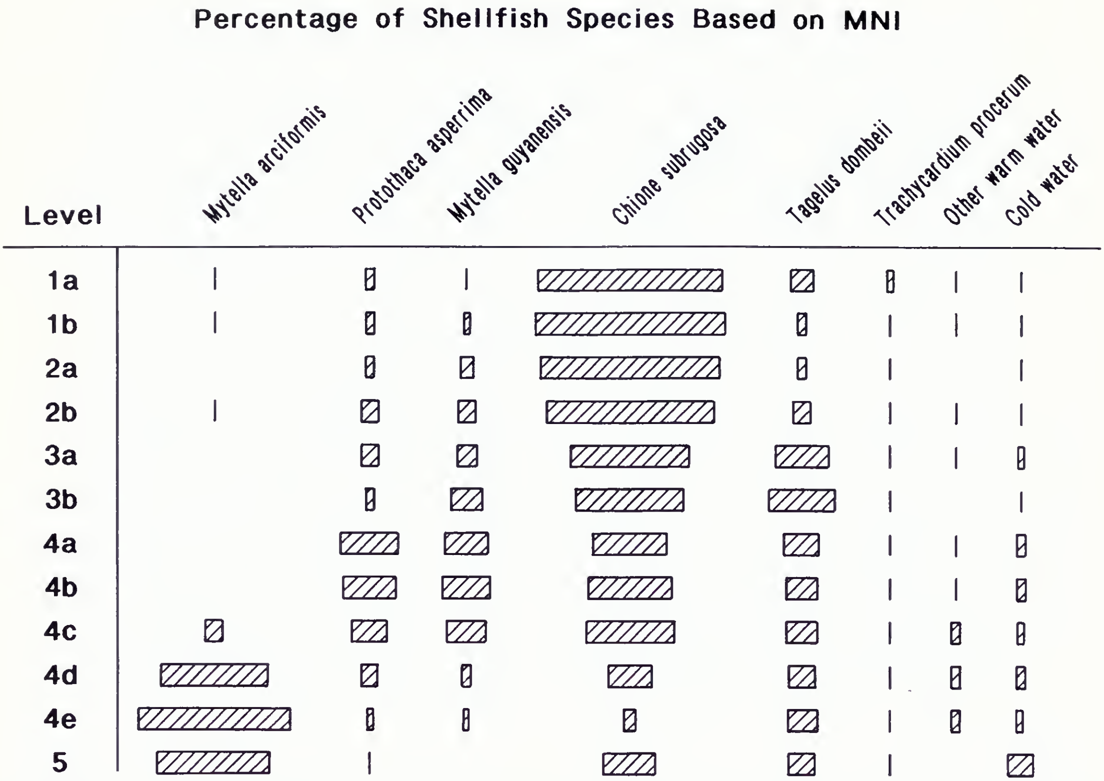

Figure 6. Diagram of shellfish species frequency through time at Almejas, based on MNI (Minimum Number of Individuals). Level 5 is the earliest level; level 1a is the latest.

confined to mud-rich substrate habitats within warmer waters much farther north, near the modern Peru–Ecuador border and beyond. Fish species identified at Almejas also argue for the presence of a local warm-water estuarine environment with one or more inlets that afforded access to the cooler offshore waters.

Subsistence

Although marine mollusks and fish were the main food source, there is some evidence of plant food use. Fragments of gourd rind (*Lagenaria siceraria*) were found in the middle levels of the cut, well below any evidence of disturbance or contamination. Immature fruits of this plant may have been used as food, and the presence of rind fragments points to the use of gourd containers. Other than gourd, only remains of wild plants were recovered from the preceramic midden. The dominant species was *algarrobo* (*Prosopis chilensis*). Seeds of this plant were very common, suggesting that the sweet bean pods, readily available from trees on the valley edges, were a source of food.

Warm-blooded vertebrates, including birds and marine and terrestrial mammals, composed an additional, relatively minor food source. Bones of rails (Rallidae), cormorants (*Phalacrocorax* spp.), mice (Cricetinae), sea lion (Otariidai), and deer were identified among the faunal remains within the stratigraphic excavation (Reitz 1995b). However, none except the mouse species is represented by more than one or two bones.

The molluscan species inventory of Almejas is unusual because it is dominated by shellfish species, which favor the muddy, silt-rich substrate typical of estuaries and are now available almost exclusively in the warm-tropical waters of the far north coast of Peru (Figs. 6 through 10). These include *Chione subrugosa* (Figs. 6 through 8), the most common species at Almejas, as well as substantial numbers of *Mytella guyanensis* (Figs. 6, 7, and 9), *Mytella arciformis* (Figs. 6, 7, and 10), *Protothaca asperrima,* and *Trachycardium procerum,* and, more rarely,

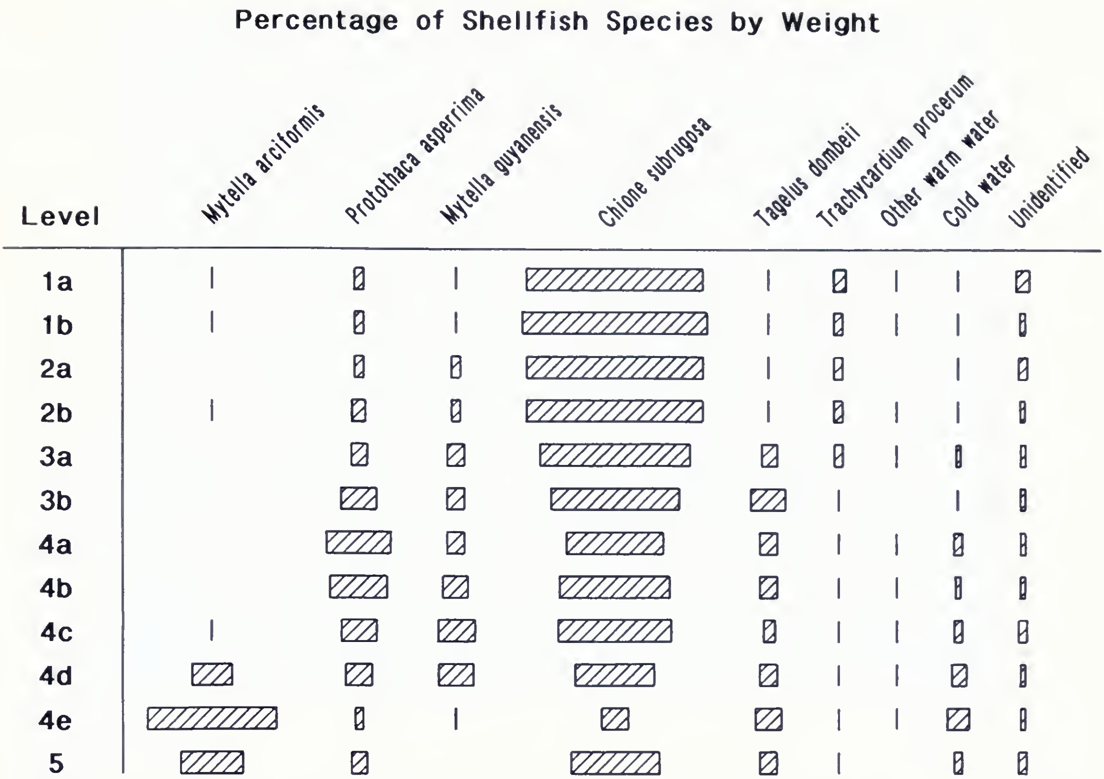

Figure 7. Diagram of shellfish species frequency through time at Almejas based on weight of sample. Level 5 is the earliest level; level 1a is the latest.

Mactra fonsecana, Nassarius luteostoma, Cerithium stercusmuscarum, and *Cerithidea albonodosa* (Figs. 6 and 7) (Keen 1971:63–610 *passim*; Olsson 1961:113–325 *passim*). Even slightly later local preceramic and early ceramic middens contain few to none of these species, which suggests that they disappeared from the area quite early. Not all shellfish from Almejas are species that inhabit exclusively a mud flat habitat. *Tagelus dombeii* (Figs. 6 and 7) is known to occur in sandy substrates (Coker, cited in Dahl 1909:160), and this species has a known range that extends northward to Panama and southward to Chile (Dall 1909:160; Keen 1971:246; Olsson 1961:351). Also significantly, shellfish typical of warm-temperate waters are represented by a number of chiton plates and shells of *Tegula atra, Brachidontes purpuratus, Thais chocolata, Choromytilus chorus,* and limpets (Figs. 6 and 7). These species characteristic of colder water were accessible in the rocky areas washed by open surf near the modern town of Puerto Casma. They were much more frequently exploited later, and came to dominate the faunal inventory of sites established in the area after the silting in and eventual desiccation of the estuary near Almejas. Clearly, the inhabitants of Almejas placed much greater emphasis on the abundant and more readily accessible shellfish within the local estuary, a rich microenvironment teeming with plant and animal life.

The medium to large bivalve shells from Almejas exhibit consistent fracture patterns (Figs. 8 to 10), which indicates they were bashed open with a simple pounding tool. Because cooked shellfish are easily opened, it seems most likely that the inhabitants of Almejas consumed local mollusks raw.

Fish species consumed by the inhabitants of Almejas also reflect the site's proximity to the resource-rich local estuarine environment. Barrier islands protect such environments from the ocean, promoting the deposition of the fine river-borne sediments that compose the component mud flats and facilitate the formation of marshes (Odum 1971:352–362). Nevertheless, estuaries experience tidal fluctuations through open-

Figure. 8. Whole and fragmentary specimens of *Chione subrugosa* showing the characteristic breakage pattern evincing live shellfish consumption.

Figure 9. Fragmentary specimens of *Mytella guyanensis* showing the characteristic breakage pattern evincing live shellfish consumption.

Figure 10. Whole and fragmentary specimens of *Mytella arciformis* showing the characteristic breakage pattern evincing live shellfish consumption.

ings that connect the estuary with a nearby bay or open ocean (Odum 1971; Reitz 1995b). The resulting environment is dynamic and much more productive than offshore waters because nutrients tend to be trapped and concentrated there, and photosynthesis occurs throughout the year (Odum 1971). Especially relevant to the Casma situation is the fact that estuaries function as nurseries for many organisms, including fish, thereby increasing their natural richness (Odum 1971:356). Adult fish may spawn in the ocean, with the larvae being carried into the estuary by tidal currents. Other adult fish may enter the estuaries to spawn, with their young remaining there until they reach maturity. Adult fish may spend more or less time within estuaries. They are attracted by the rich biomass as a food source, yet temporarily intolerable temperatures or salinity may induce them to leave the estuarine ecosystem for more stable offshore water (Reitz 1995b; Hackner et al. 1976, cited in Reitz 1995b). Other species that frequent shallow near-shore waters may be attracted to the vicinity of estuary inlets and even into the estuary because of the richer food supply available in such zones.

Since the estuary near Almejas was such a critical part of the ecosystem which supported the site's inhabitants, it is important to assess the fish species relative to their potential role within this feature of the local environment. To accomplish this, we used Reitz's (1995b) excellent review and synthesis of the available habitat data for the fish species identified from Almejas, which draws primarily on Chirichigno (1974, 1982) and Schweigger (1964) as well as additional sources (DEIS 1978; Hoese and Moore 1977; Moreno and Castilla n.d.—all cited in Reitz 1995b). The results are presented in Tables 2 through 4. These tables reveal that fish species consumed at Almejas fall into three principal groups: species that frequent estuaries, species native to the warm-temperate waters of the Peruvian Current, and mixed-habitat species that are known to inhabit both warm-temperate and warm-tropical waters. Significantly, only three species that are more typical of warm-tropical waters were identified among the faunal remains. Several estuarine species were initially classified as warm-tropical species (Reitz 1995b); however, assessment of fish habitat data in light of the reconstructed local estuarine

TABLE 2. Fish species identified from the column sample.

Species	NISP	MNI No.	MNI (%)	Weight, g	Biomass* kg	Biomass* (%)
Estuarine fish species						
Elops affinis (ladyfish)	9	2	(1.54)	0.039	0.0122	(1.79)
Clupeidae (herrings)	806	38	(29.23)	6.639	0.1713	(25.18)
Engraulidae (anchovies)	4,809	67	(51.54)	8.840	0.2142	(31.49)
Ariidae (sea catfishes)	4	3	(2.31)	0.140	0.0032	(0.47)
Bairdiella spp. (silver perch)	1	1	(0.77)	0.030	0.0029	(0.43)
Mugil spp. (mullet, *lisa*)	105	9	(6.92)	1.128	0.0322	(4.73)
Subtotal		120	(92.31)		0.4360	(64.09)
Warm-temperate fish species						
Myliobatidae (eagle rays)	4	2	(1.54)	0.110	0.0198	(2.91)
Sciaena spp. (*lorna*)	3	3	(2.31)	0.028	0.0037	(0.54)
Subtotal		**5**	**(3.85)**		**0.0235**	**(3.45)**
Mixed-habitat fish species						
Elasmobranchiomorphi (cartilaginous fishes)	1	1	(0.77)	0.009	0.0022	(0.32)
Dasyatidae (stingrays)	3	1	(0.77)	0.070	0.0128	(1.88)
Muraenidae (morays)	1	1	(0.77)	0.010	0.0008	(0.12)
Cynoscion spp. (seatrout)	1	1	(0.77)	0.020	0.0022	(0.32)
Subtotal		4	(3.08)		0.0180	(2.64)
Warm-tropical fish species						
Gerridae (*Mojarras*)	1	1	(0.77)	0.009	0.0006	(0.09)
Subtotal		1	(0.77)		0.0006	(0.09)
Unidentified fish	849			8.340	0.2022	(29.72)

Abbreviations: NISP, number of identified species; MNI, minimum number of individuals.
* Biomass values are based on calculations made by Reitz (1995b; Reitz and Cordier 1983; Reitz et al. 1987).

environment led the authors to conclude that virtually all of these species should more appropriately be viewed as estuary dwellers. The differences between the fish species identified from the column sample as compared to the general excavation (Tables 2 and 3) are particularly noteworthy in this regard. The fish remains from the column sample (no. 10 and no. 25 geological sieves) strongly reflect exploitation of the estuary, where small fishes, both young fishes and small adult fishes, could be easily taken. The small herrings and anchovies are included in Table 2 as estuarine fish because some species within both families are known to frequent estuaries and because their consistent, small size within the archaeological sample suggests that the estuary served as their nursery. In contrast, adults of these two species are known to frequent the offshore waters of the Peruvian Current; therefore, the herring and anchovy remains recovered from the general excavation (¼ in. screen) were included among the warm-temperate fish in Table 3. Tables 2 and 3 also reveal the paramount importance of the estuary as a food source. More than 64% of the fish biomass reconstructed for the column sample came from estuarine fishes, versus 3.45% for the warm-temperate fishes and 2.64% for the mixed-habitat fishes (Table 2). More balance can be seen with respect to the fish biomass reconstructed for the general excavation, with almost 24% comprised of estuarine species, over 21% comprised of warm-temperate species, and over 14% comprised of mixed-habitat fish (Table 3). These proportions are in keeping with the reconstructed subsistence scenario. Adult mullet and sea catfish are known to inhabit estuaries and have been classified accordingly. The other adult species represented by vertebrate remains from the general

TABLE 3. Fish species identified from the general excavation.

Species	NISP	MNI		Weight, g	Biomass*	
		No.	(%)		kg	(%)
Estuarine fish species						
Albula vulpes (bonefish)	1	1	(0.97)	0.080	0.0041	(0.10)
Ariidae (sea catfishes)	220	21	(20.39)	39.170	0.6858	(17.26)
Micropogonias spp. (croaker)	9	5	(4.85)	2.760	0.0949	(2.39)
Mugil spp. (mullet, *lisa*)	114	15	(14.56)	8.000	0.1665	(4.19)
Subtotal		42	(40.77)	50.010	0.5913	(23.94)
Warm-temperate fish species						
Myliobatidae (eagle rays)	1	1	(0.97)	0.430	0.0609	(1.53)
Clupeidae (herrings)	150	11	(10.68)	4.669	0.1089	(2.74)
Engraulidae (anchovies)	9	4	(3.88)	0.168	0.0081	(0.20)
Paralabrax spp. (*cabrilla*)	7	4	(3.88)	0.560	0.0094	(0.24)
Trachurus murphyi (jack mackerel, *jurel*)	9	4	(3.88)	2.350	0.0885	(2.23)
Anisotremus spp. (*sargo*)	1	1	(0.97)	0.080	0.0030	(0.08)
Sciaenidae (drums)	5			0.760	0.0318	(0.80)
Paralonchurus spp. (*coco*)	28	5	(4.85)	9.080	0.2642	(6.65)
Sciaena spp. (*lorna*)	24	8	(7.77)	11.260	0.2421	(6.09)
Bodianus spp. (hogfish)	1	1	(0.97)	0.270	0.0093	(0.23)
Sarda spp. (*bonito*)	3	1	(0.97)	0.790	0.0226	(0.57)
Subtotal		40	(38.83)	30.417	0.8488	(21.36)
Mixed habitat fish species						
Carcharhinidae (requiem sharks)	11	3	(2.91)	1.360	0.1864	(4.69)
Dasyatidae (stingrays)	9	3	(2.91)	1.720	0.2249	(5.66)
Muraenidae (morays)	1	1	(0.97)	0.030	0.0019	(0.05)
Serranidae (sea basses)	2			0.200	0.0033	(0.08)
Carangidae (jacks)	1			0.130	0.0065	(0.16)
Trachinotus spp. (pompano)	1	1	(0.97)	0.050	0.0028	(0.07)
Cynoscion spp. (seatrout)	13	6	(5.83)	1.620	0.0759	(1.91)
Bothidae (flounders)	6	3	(2.91)	2.520	0.0639	(1.61)
Subtotal		17	(16.50)	7.630	0.5656	(14.24)
Warm-tropical fish species						
Epinephelus spp. (grouper)	12	3	(2.91)	2.630	0.0522	(1.31)
Gerridae (*Mojarras*)	3	1	(0.97)	0.210	0.0075	(0.19)
Subtotal		4	(3.88)	2.840	0.0597	(1.50)
Unidentified fish	1,810			111.900	1.5473	38.95

Abbreviations: NISP, number of identified species; MNI, minimum number of individuals.
* Biomass values are based on calculations made by Reitz (1995; Reitz and Cordier 1983; Reitz et al. 1987).

excavation are potential offshore species that may have been taken in the cooler waters of the open ocean, near estuary inlets because of the richer nutrients, or even within the estuary—the richest of the three potential environments. This is especially likely for *sargo* (*Anisotremus* spp.), seatrout (*Cynoscion* spp.), *coco* (*Paralonchurus* spp.), *lorna* (*Sciaena* spp.), flounders (Bothidae family), and members of the jack family (Carangidae), all of which are known to inhabit shallow inshore waters.

Environment

The archaeological data from Almejas must be viewed in relation to three radiocarbon dates from its midden: 5245 ± 75 B.C. (UGa-4518), 5270 ± 70 B.C. (UGa-4519), and 4925 ± 105 B.C. (UGa-4539) (Table 1). These dates cluster around 5000 B.C. (uncalibrated). Several other sites along the western coast of South America are known to date as early as Almejas or earlier. The earliest coastal sites that show heavy reli-

TABLE 4. Combined biomass values for fish species identified at Almejas.*

Sample	Estuarine fish species kg	Estuarine fish species (%)	Warm-temperate fish species kg	Warm-temperate fish species (%)	Mixed-habitat fish species kg	Mixed-habitat fish species (%)	Warm-tropical fish species kg	Warm-tropical fish species (%)	Unidentified fishes kg	Unidentified fishes (%)
General excavation	0.9513	(23.94)	0.8488	(21.36)	0.5656	(14.24)	0.0597	(1.50)	1.5473	(38.95)
Column sample	0.4360	(64.09)	0.0235	(3.45)	0.0180	(2.64)	0.0006	(0.09)	0.2022	(29.72)
Adjusted column†	5.7988	(64.09)	0.3125	(3.45)	0.2394	(2.64)	0.0080	(0.09)	2.6893	(29.72)
Total	6.7501	(51.84)	1.1613	(8.92)	0.8050	(6.18)	0.0677	(0.52)	4.2366	(32.54)

* Biomass values are based on calculations made by Reitz (1995b; Reitz and Cordier 1983; Reitz et al. 1987).

† The column sample values were adjusted upward based on the proportion that the column sample volume (109 liters) represented of the total volume of the stratigraphic excavation (1,454 liters), resulting in a factor of 13.3.

ance on marine resources are known from the far north of Peru near Talara (Richardson 1978, 1981), in southern Ecuador (Stothert 1985), from far southern Peru near Ilo (Sandweiss et al. 1989), and from northern Chile near Antofagasta (Aldenderfer 1989:117–144; Llagostera Martinez 1979; Richardson 1981, 1994:38–39). These sites tend to be located where the continental shelf is narrow, thereby minimizing the impact of the subsequent shoreline transgression believed to have inundated ancient shoreline sites where the shelf is wide (Richardson 1981). These sites also tend to have faunal remains consistent with their geographic location.

Three additional sites or site complexes are more comparable to Almejas based on their radiocarbon dates and because of the presence of what have been described as thermally anomalous fish and/or shellfish species. These include the Paijan complex sites, located well inland between the Chicama and Jequetepeque Valleys, which have been dated to approximately 8550–6050 B.C. (Chauchat 1988; Reitz 1995a, 1995b), as well as Ostra Base Camp and Pampa las Salinas, located north of the Santa River mouth, with radiocarbon dates of ca. 6000 B.C. (Reitz 1995a, 1995b, 2001; Sandweiss et al. 1983, 1986, 1996).

The data from Almejas are especially relevant to the controversial issues of when the sea level attained its present level and the antiquity of the present climatic regime and its associated current patterns (DeVries and Wells 1990; DeVries et al. 1997; Kerr 1999; Rodbell et al. 1999; Rollins et al. 1986, 1997; Sandweiss 1986; Sandweiss et al. 1983, 1996, 1997, 1998, 1999; Wells 1988:160–176; Wells and Noller 1997). The authors' reconstruction of the environment of Almejas at the time of its occupation suggests that the sea level and climatic conditions in effect today are in fact quite old.

The warm-temperate water of the Peruvian Current was likely present off the Casma Valley coast at least by about 7000 years ago, when Almejas was occupied. Arguments for considerable antiquity for the current climatic regime are based on the faunal inventory of Almejas, subsistence activities practiced at the site, and preservation within the site. Both fish and shellfish species provide evidence that cold water was readily accessible from the site. Additional evidence that these species characteristic of warm-temperate water were taken by the inhabitants of Almejas comes from the human skeleton, which was characterized by auditory exostoses, bony growths that develop in the ear canal as a result of repeated exposure to cold water (Kennedy 1986). Finally, the preservation of fragile plant material—including the *junco* burial wrapping, gourd rind, and *algarrobo* seeds—within the Almejas midden argues for a near-rainless climate of the type that exists today. Without the Peruvian Current offshore, the climate would have been significantly wetter, and preservation would have been negatively affected.

Sea level was probably close to or slightly higher than current levels at the time Almejas was in use (Wells 1988:161–162). Evidence for this comes from the fact that an estuary was present at the mouth of the Casma River at this time (Wells 1988:161–162). Formation of this estuary depended on the sea level being at or slightly above its present height. Ample evidence for the existence and exploitation of this rich estuarine environment comes from the many warm-water mud flat molluscan species and the estuarine fish species, especially the immature individuals recovered through fine screening, that make the Almejas faunal inventory so remarkable. These species most likely became established in the estuarine environment when free-floating or free-swimming molluscan larvae and fish traveled south within the warm Ecuadorian Countercurrent during an infrequent El Niño event. They would have thrived within the shallow, nutrient-rich, sun-warmed estuarine environment (DeVries and Wells 1990; Smith 1944:v). The Casma Valley is an especially favorable place for this to occur because of the large number of sunny days (ONERN 1972:50).

Warm-temperate species were available on the rocky headlands and slightly offshore, but mud flat estuarine species were clearly preferred. This preference probably reflects both their abundance in the rich estuarine habitat and their ease of capture, especially for people who apparently lacked a well-developed fishing technology. Nutrients from the estuarine environment would have spilled out into the ocean, thereby attracting warm-temperate fish and making them more accessible to the people of Almejas.

Ironically, the same sea level rise or transgression that initially facilitated development of the estuarine environment that likely attracted the inhabitants of Almejas to settle nearby also triggered deposition of river-borne sediments (DeVries and Wells 1990; Wells 1988:172–176). Gradual filling by these sediments ultimately eliminated the estuary—a local environmental change that also likely led to the abandonment of Almejas. Similar sequences of estuary development and backfilling by river-borne sediment likely occurred in other coastal areas, thereby also explaining occasional occurrences of colonies of tropical fauna of relatively long duration within an otherwise temperate zone. This would also explain why estuaries were once more common, but are now rare.

Variation in the frequency of specific shellfish species through time may be correlated with the gradual silting in of the estuarine environment that eventually led to its disappearance and the abandonment of Almejas. The charts in Figures 6 and 7 clearly reveal that six species comprise most of the molluscan inventory: *Mytella arciformis, Protothaca asperima, Mytella guayanensis, Chione subrugosa, Tagelus dombeii,* and *Trachycardium procerum,* with the latter showing a significant presence more clearly in Figure 7. It is also readily apparent that *Mytella arciformis* dominates the shellfish inventory in the earliest levels and that *Protothaca asperima* and *Mytella guayanensis* exhibit their greatest frequencies of occurrence slightly later within the stratigraphic sequence. *Tagelus dombeii* peaks in frequency even later in the sequence, whereas *Chione subrugosa,* the most abundant mollusk overall, exhibits its highest frequency toward the end of the stratigraphic sequence.

Habitat data are rarely supplied in great detail, but the data available for the principal species indicate that two of the three species that predominate in the early and early-middle portion of the sequence are known to occur in considerably deeper water than most species that predominate in the late and middle-late portion of the sequence. Specifically, the habitat of *Mytella arciformis* has been described as "six fathoms, mud" (Hertlein and Strong 1946:72), and *Prothaca asperrima* has been described as occurring "in sandy mud at a depth of 13 fathoms" (Hertlein and Strong 1946:187). When specific depth measurements are provided for one species with peak frequencies toward the latter part of the sequence, the habitat depth is much shallower. Live specimens of *Tagelus dombeii* are described as being "taken in sand under three or four feet of water" (Coker, quoted in Dahl 1909:160). However, live individuals of *Trachycardium procerum,* which are slightly more abundant during the latter portion of the sequence, were "found in coarse sand in from four to six fathoms of water" (Sowerby 1833: 83), and each of the six dominant species has been described by one or more experts as occurring in shallow water, lagoons, shallow lagoons, on mud flats, at low water, and in intertidal zones, indicating that all could be found at times in relatively shallow water (Hertlein and Strong 1946:72–191 *passim*; Keen 1971: 63–246 *passim*; Olsson 1961:298; Soot-Ryen 1955:53, 55; Sowerby 1835:41).

When the available data on the geographic distribution of the principal species are considered, the three species with peak frequencies earlier in the sequence appear more narrowly confined to warm-tropical zones. *Mytella arciformis* is known from El Salvador to Ecuador or Peru (Hertlein and Strong 1946:72; Keen 1971:63), *Mytella guayanensis* is known from Mexico or the Gulf of California to northern

Peru (Hertlein and Strong 1946:72–73; Keen 1971:63; Soot-Ryen 1955:53, 55), and *Protothaca asperrima* is known from California to Peru—more commonly northern Peru (Dahl 1909:158; Hertlein and Strong 1946:187; Keen 1971:193). In contrast, *Tagelus dombeii* is known from Panama to Chile (Dahl 1909:160; Keen 1971:246; Olsson 1961:351); *Chione subrugosa* is described by Dahl (1909:158) as occurring from the Gulf of California to Valparaiso, Chile (although other experts describe a more northern range, from the Gulf of California to Peru: Hertlein and Strong 1946; Keen 1971:190; Olsson 1961:298); and *Trachycardium procerum* is known from the Gulf of California to northern Chile or Chile (Keen 1971: 155; Olsson 1961:247–248). These data likely reflect the greater tolerance of *Chione subrugosa,* and especially *Tagelus dombeii* and *Trachycardium procerum,* to more varied environments, including cooler water. This may have allowed these species to survive as the estuary filled with silt, became smaller in area, and was likely more impacted by the cooler water of the adjacent open ocean at its outlet. Such an interpretation might also explain the relatively rare but continued presence of remains of these three species at later preceramic and Initial Period (1800–900 B.C.) sites.

Discussion and Conclusions

As a result of recent fieldwork and research, other archaeological sites similar to Almejas have been discovered that date quite early within the Andean sequence and have yielded faunal assemblages that reflect the presence of species not currently typical of their respective latitudes. These include the Paijan complex sites north of the Chicama Valley and the sites of Pampa las Salinas and Ostra Base Camp north of the Santa River mouth (Andrus et al. 2002; Chauchat 1976, 1978, 1988; Reitz 1995a, 1995b, 2001; Rollins et al. 1986; Sandweiss et al. 1983, 1996).

Initially, the sites north of Santa attracted attention because of the presence of shellfish currently known to inhabit warm-tropical waters (Rollins et al. 1986; Sandweiss et al. 1983), as did the site of Almejas. These data from the Santa sites in particular were initially used to argue for the continuous presence of warmer currents much further south, an absence of ENSO events, and a corresponding wetter climatic regime much different from today's climate (Rollins et al. 1986; Sandweiss et al. 1983). As additional faunal material was analyzed from the Paijan complex sites, from the Santa area, and from Almejas in Casma, fish species were identified that are not currently typical of these areas. These results have been used by many of the same investigators as further evidence of the presence of warmer offshore waters (Andrus et al. 2002; Reitz 1995a, 1995b, 2001; Sandweiss et al. 1996).

An alternative scenario maintains that the current climatic regime, including periodic ENSO events, is quite ancient. Indeed, evidence from the far south coast site of Quebrada Tacahuay indicates that ENSO events were present at least as early as the late Pleistocene (Keefer et al. 1998). The seemingly out-of-place species represent colonies of thermally anomalous fauna whose larvae were carried southward within the warm currents of a periodic ENSO event (S. Pozorski and T. Pozorski 1995; DeVries et al. 1997; Wells and Noller 1997). As the sea level rose to approximately modern limits, estuaries formed at the mouths of some rivers, and the resultant shallow, sun-warmed, nutrient-rich waters readily supported species adapted to warmer estuarine waters (DeVries et al. 1997; DeVries and Wells 1990; Wells and Noller 1997). Also according to this scenario, ENSO events were essential to stock the estuaries with appropriate fish and shellfish species, after which time the cooler offshore Peruvian Current would have returned. Once introduced, these warm-tropical shellfish and fish species would have flourished in these estuaries as long as local environmental conditions remained favorable. Subsequent ENSO events could potentially have introduced additional shellfish and fish species, but such events were not essential for the survival of these species in their localized estuarine environments. Hence, fluctuations in the periodicity of ENSO events are not especially relevant with respect to the survival of these thermally anomalous shellfishes and fishes in estuarine conditions. The critical variable was the maintenance of local environmental conditions. Ironically, the same sea level rise that precipitated the formation of estuarine environments was also a causal factor in their disappearance as river-borne sediments infilled these coastal features. This explains the near absence of estuaries along the modern Peruvian coast.

Clearly, faunal data from the Paijan complex sites, the Santa sites, and Almejas are critical to address the issue of past climate in the vicinity of these sites. In assessing these fauna, particularly the fish species, the tendency has been to emphasize, and at times "force" the data to conform to, the perceived dichotomy between (1) species that are characteristic of the warmer water off the coast of Ecuador and northern Peru and have been classified as warm-tropical species and (2) species that are characteristic of the cooler water of the Peruvian Current and have been classified as warm-temperate species (Reitz 1995a, 1995b, 2001; Sandweiss et al. 1996). To Reitz's credit, she discusses the probable existence of estuaries in the respective vicinities of Ostra Base Camp, Almejas, and Paijan complex sites, states the important characteristics of estuaries and their fauna, meticulously reviews habitat data for the species identified at the sites, and describes many of the fish species identified at the sites as estuarine fishes. Nevertheless, in the final analysis, she categorizes these typically estuarine fishes as warm-tropical species (Reitz 1995a, 1995b, 2001). In contrast to this approach, we believe that the marine fauna of the three sites under consideration here should be examined in light of the prevalent environments at the sites: estuaries and offshore warm-temperate waters.

Tables used by Sandweiss et al. (1996:Table 3; Reitz 1995a:Table 1, 1995b:Table 2) to show broad trends on the basis of MNI (minimum number of individuals) percentages for what they classified as warm-tropical versus warm-temperate fish species resulted in high values for warm-tropical species from Paijan sites, Ostra Base Camp in the Santa area, and Almejas. Although nonmarine vertebrates figured more prominently in the subsistence regimen of the Paijan sites, the identifiable fish (MNI = 113) were assessed at 97.3% warm-tropical species versus 2.6% warm-temperate species. For the Ostra Base Camp site, the values were 64.2% warm-tropical species and 35.8% warm-temperate species (MNI = 120). For Almejas, the values also included mixed-habitat species (species known to occur in both warm-tropical and warm-temperate waters), and the column sample and general sample were treated separately (Reitz 1995a, 1995b). The Almejas results, as tabulated by Reitz (1995a, 1995b), were as follows: 40% warm-tropical, 35% warm-temperate, and 15% mixed for the general excavation (MNI = 114), and 12% warm-tropical, 84% warm-temperate, and 4% mixed for the column sample (MNI = 131).

These data presented by Reitz (1995a, 1995b, 2001) and Sandweiss et al. (1996) would seem to indicate the presence of warm offshore waters in the vicinities of the three sites. However, closer examination of the individual fish species and their habitats suggests to the authors that most fishes classified as warm-tropical species are more appropriately classified as estuarine species. This has already been demonstrated for Almejas (described above), for which detailed data are available to the authors. Once estuarine species have been reclassified, few species identified at Almejas remain within the warm-tropical category (Tables 2 to 4). Detailed species lists for Paijan complex sites have not been published; however, Reitz (1995b, 2001) describes sea catfish (Ariidae) and *lisa* (mullet, *Mugil* spp.) as the most common fishes, with bonefish (*Albula vulpes*) and croaker (*Micropogonias* spp.) common in some assemblages and small numbers of *mojarra* (Gerridae, *Eucinostomus* spp.) and porgy (Sparidae) also identified. Herring (Clupeidae), anchovy (Engraulidae), and *coco* (*Paralonchurus* spp.) were also present. Among these species listed for the Paijan complex sites, all are commonly found in estuaries except adult herring, anchovy, and *coco* (*Paralonchurus* spp.), which are warm-temperate species, and *mojarra* (Gerridae), the only fish listed that is typically taken in warm-tropical waters (Reitz 1995b). Fewer data are available concerning fish species identified at Ostra Base Camp; however, Reitz (1995a, 2001) mentions bonefish, sea catfish, *lisa* (mullet), and puffer (*Spheroides annulatus*) as the primary species, with warm-temperate fishes relatively rare. All of these primary species mentioned for Ostra Base Camp are estuarine fishes (Reitz 1995b, 2001).

Data from the fine-screened column sample we excavated at Almejas were also critical to our realization that subsistence activities at this site were focused primarily on the local estuarine ecosystem and its component resources. These tiny bones represent small fishes and especially the young of species that typically use estuaries as nurseries. Their importance to the inhabitants of Almejas is especially evident when their respective biomass values are adjusted to compensate for the difference in volume between the column sample and the general excavation (Table 4). Mud flat mollusks, also typical of estuaries, composed the other major source of food for the people of Almejas. These shellfishes provide additional evidence of the importance of this resource zone to their subsistence. The location of the site and the inhabitants' decision to settle near the mouth of the Casma River were likely predicated on the rich and abundant estuarine resources, and the site was likely abandoned once the estuary silted in and disappeared. Nevertheless, the presence of substantial amounts of warm-temperate fish species along with a number of molluscan species known to inhabit warm-temperate waters provides evidence that warm-temperate species were accessible to and exploited by the site's occupants. These species also document the presence of the cooler offshore waters of the Peruvian Current in the vicinity of the site.

The data presented and reviewed here reveal that the site of Almejas is unusual for several reasons. It represents one of the earliest marine-oriented sites along the north and central coast of Peru, predating by at least 2000 years most of the larger, better known sites dating to the Late Preceramic Period. Its shellfish and fish inventories also distinguish Almejas from most known preceramic sites and provide critical evidence that subsistence activities by the site's inhabitants focused on a local estuarine environment complemented by some exploitation of warm-temperate offshore waters. Coincident geomorphological data indicate that modern sea level had been attained by the time Almejas was occupied, resulting in the formation of the estuarine environment that attracted these early settlers. Finally, the faunal remains, the geomorphological data, and archaeological evidence of optimum preservation argue that the ENSO phenomenon has been in existence since at least 5000 B.C., and probably much longer.

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Literature Cited

Aldenderfer, M. 1989. The Archaic period in the south-central Andes. Journal of World Prehistory, **3:** 117–158.

Andrus, C. F. T., D. E. Crowe, D. H. Sandweiss, E. J. Reitz, and C. S. Romanek. 2002. Otolith δ18O record of mid-Holocene sea surface temperatures in Peru. Science, **295:** 1508–1511.

Arriaza, B. 1995. Beyond Death: The Chinchorro Mummies of Ancient Chile. Smithsonian Institution Press, Washington, D.C.

Bass, W. 1987. Human Osteology: A Laboratory and Field Manual, 3rd ed. Special Publication No. 2, Missouri Archaeological Society, Columbia.

Bird, J., and J. Hyslop. 1985. The Preceramic Excavations at the Huaca Prieta Chicama Valley, Peru. Anthropological Papers, vol. 62, part 1. American Museum of Natural History, New York.

Brothwell, D. R. 1981. Digging Up Bones, 3rd ed. Cornell University Press, Ithaca, New York.

Chauchat, C. 1978a. The Paijan complex, Pampa de Cupisnique, Peru. Ñawpa Pacha, **13:** 85–96.

———. 1978b. Additional observations on the Paijan complex. Ñawpa Pacha, **16:** 51–64.

———. 1988. Early hunter-gatherers on the Peruvian coast, pp. 41–66. *In* R. Keatinge, ed., Peruvian Prehistory. Cambridge University Press, Cambridge, U.K.

Chirichigno, F. N. 1974. Clave para identificar los peces marinos del Peru. Informe No. 44. Instituto del Mar del Peru, Callao, Peru.

———. 1982. Catálogo de especies marinas de interes económico actual o potencial para América Latina: Parte II. Pacífico centro y suroriental. FAU, Rome.

Dall, W. H. 1909. Report on a collection of shells from Peru, with a summary of the littoral marine Mollusca of the Peruvian Zoological Province. Proceedings of the United States National Museum, **37**(1704): 147–294, Pl. 20–28.

DEIS. 1978. Draft Environmental Impact Statement for Preferred Alternative Location for a Fleet Ballistic Missile (FBM) Submarine Support Base: Appendix 2. Department of the Navy, Washington, D.C.

DeVries, T., L. Ortlieb, A. Diaz, L. Wells, and C. Hillaire-Marcel. 1997. Determining the early history of El Niño. Science, **276:** 965–966.

DeVries, T., and L. Wells. 1990. Thermally-anomalous Holocene molluscan assemblages from coastal Peru: Evidence for paleogegraphic, not climatic change. Palaeography, Palaeoclimatology, Palaeoecology, **81:** 11–37.

Engel, F. 1976. An Ancient World Preserved. Crown Publishers, New York.

———. 1981. Prehistoric Andean Ecology: Man, Settlement, and Environment in the Andes. The Deep South. Humanities Press, New York.

Feldman, R. 1980. Aspero, Peru: Architecture, Subsistence Economy, and Other Artifacts of a Preceramic Maritime Chiefdom. Ph.D. diss., Department of Anthropology, Harvard University, Cambridge, Massachusetts.

Fung Pineda, R. 1988. The Late Preceramic and Initial Period, pp. 67–96. *In* R. Keatinge, ed., Peruvian Prehistory. Cambridge University Press, Cambridge, U.K.

Genoves, S. 1967. Proportionality of long bones and their relation to stature among Mesoamericans. American Journal of Physical Anthropology, **26:** 67–78.

Grieder, T., A. B. Mendoza, C. E. Smith, Jr., and R. Malina. 1988. La Galgada, Peru: A Preceramic Culture in Transition. University of Texas Press, Austin.

Hertlein, L., and A. M. Strong. 1946. Eastern Pacific expeditions of the New York Zoological Society: Mollusks from the west coast of Mexico and Central America. Zoologica: Scientific Contributions of the New York Zoological Society, **31**(2): 53–77.

Hoese, H. D., and R. H. Moore. 1977. Fishes of the Gulf of Mexico: Texas, Louisiana and Adjacent Waters. Texas A & M University Press, College Station.

Joralemon, D., and D. Sharon. 1993. Sorcery and Shamanism: Curanderos and Clients in Northern Peru. University of Utah Press, Salt Lake City.

Keefer, D. K., S. D. deFrance, M. E. Moseley, J. B. Richardson III, D. Satterlee, and A. Day-Lewis. 1998. Early maritime economy and El Niño events at Quebrada Tacahuay, Peru. Science, **281:** 1833–1835.

Keen, A. M. 1971. Sea Shells of Tropical West America: Marine Mollusks from Baja California to Peru. Stanford University Press, Stanford, Calif.

Kennedy, G. 1986. The relationship between auditory exostoses and cold water: A latitudinal analysis. American Journal of Physical Anthropology, **71:** 401–415.

Kerr, R. A. 1999. El Niño grew strong as cultures were born. Science, **283:** 467–468.

Lanning, E. 1967. Peru Before the Incas. Prentice-Hall, Englewood Cliffs, N.J.

Llagostera Martinez, A. 1979. 9700 years of maritime subsistence on the Pacific: An analysis by means of bioindicators in the north of Chile. American Antiquity, **44:** 309–324.

Moreno, C. A., and J. C. Castilla. n.d. Guía para el reconocimiento y observación de peces de Chile. Santiago: Editora Nacional Gabriela Mistral, Santiago, Chile.

Moseley, M. 1983. Central Andean civilization, pp. 179–239. *In* J. Jennings, ed., Ancient South Americans. W. H. Freeman and Company, San Francisco.

———. 1992. The Incas and Their Ancestors: The Archaeology of Peru. Thames and Hudson, London.

Odum, E. P. 1971. Fundamentals of Ecology. W. B. Saunders Co., Philadephia.

Olsson, A. 1961. Mollusks of the Tropical Eastern Pacific, Particularly from the Southern Half of the Panamic-Pacific Faunal Province (Panama to Peru): Panamic-Pacific Pelecypoda. Paleontological Research Institution, Ithaca, N.Y.

ONERN (Oficina Nacional de Evaluación de Recursos Naturales). 1972. Inventario, evaluación y uso racional de los recursos naturales de la costa: Cuencas de los Ríos Casma, Culebras y Huarmey, vol. 1. Oficina Nacional de Evaluación de Recursos Naturales, Lima, Peru.

Pozorski, S., and T. Pozorski. 1979. Alto Salaverry: A Peruvian coastal Preceramic site. Annals of Carnegie Museum, **48:** 337–375.

———. 1987. Early Settlement and Subsistence in the Casma Valley, Peru. University of Iowa Press, Iowa City.

———. 1995. Paleoenvironment at Almejas, a mid-Holocene site in the Casma Valley, Peru. Paper presented at the 60th Annual Meeting of the Society for American Archaeology, Minneapolis, Minnesota.

Quilter, J. 1989. Life and Death at Paloma: Society and Mortuary Practices in a Preceramic Peruvian Village. University of Iowa Press, Iowa City.

Reitz, E. J. 1995a. Environmental Change at Ostra Base Camp: The Vertebrate Faunal Evidence. Paper presented at the 60th Annual Meeting of the Society for American Archaeology, Minneapolis, Minnesota.

———. 1995b. Environmental change at Almejas, Peru. Manuscript on file, University of Georgia Museum of Natural History, Athens.

———. 2001. Fishing in Peru between 10000 and 3750 BP. International Journal of Osteoarchaeology, **11:** 163–171.

Reitz, E. J., and D. Cordier. 1983. Use of allometry in zooarcheological analysis, pp. 237–252. *In* J. Clutton-Brock and C. Grigson, eds., Animals and Archaeology: Shell Middens, Fishes, and Birds. BAR International Series 183, Oxford, U.K.

Reitz, E. J., I. R. Quitmyer, H. S. Hale, S. J. Scudder, and E. S. Wing. 1987. Applications of allometry to zooarchaeology. American Antiquity, **52**(2): 304–317.

Richardson, J. 1978. Early man on the Peruvian north coast, early maritime exploitation and the Pleistocene and Holocene environment, pp. 247–259. *In* A. Bryan, ed., Early Man in America from a Circum-Pacific Perspective. University of Alberta Press, Edmonton.

———. 1981. Modeling the development of sedentary maritime economies on the coast of Peru: A preliminary statement. Annals of Carnegie Museum, **50:** 139–150.

———. 1994. People of the Andes. Smithsonian Exploring the Ancient World, J. Sabloff, series ed. St. Remy Press and Smithsonian Institution Press, Montreal and Washington, D.C.

Rodbell, D. T., G. O. Seltzer, D. M. Anderson, M. B. Abbott, D. B. Enfield, and J. H. Newman. 1999. An approximately 15,000-year record of El Niño-driven alluviation in southwestern Ecuador. Science, **283:** 516–520.

Rollins, H., J. Richardson, and D. Sandweiss. 1986. The birth of El Niño: Geoarchaeological evidence and implications. Geoarchaeology, **1:** 3–15.

Rollins, H. B., D. H. Sandweiss, U. Brand, and J. C. Rollins. 1987. Growth increment and stable isotope analysis of marine bivalves: Implications for the geoarchaeological record of El Niño. Geoarchaeology, **2**(3): 181–197.

Sandweiss, D. H. 1986. The beach ridges at Santa, Peru: El Niño, uplift, and prehistory. Geoarchaeology: An International Journal, **1:** 17–28.

Sandweiss, D. H., K. Maasch, and D. Anderson. 1999. Transitions in the Mid-Holocene. Science, **283:** 499–500.

Sandweiss, D. H., K. A. Maasch, D. F. Belknap, J. B. Richardson III, and H. Rollins. 1998. Discussion of 'The Santa Beach Ridge Complex' (Lisa E. Wells, 1996). Journal of Coastal Research **14**(1): 367–373.

Sandweiss, D. H., J. Richardson III, E. Reitz, J. Hsu, and R. Feldman. 1989. Early maritime adaptations in the Andes: Preliminary studies at the Ring site, pp. 35–84. *In* D. Rice and C. Stanish, eds., Ecology, Settlement and History in the Osmore Drainage, Peru. BAR International Series 545, Part 1.

Sandweiss, D. H., J. Richardson III, E. Reitz, H. Rollins, and K. Maasch. 1996. Geoarchaeological evidence from Peru for a 5000 years b.p. onset of El Niño. Science, **273:** 1531–1533.

———. 1997. Determining the early history of El Niño. Science, **276:** 966–967.

Sandweiss, D. H., H. Rollins, and J. Richardson III. 1983. Landscape alteration and prehistoric human occupation on the north coast of Peru. Annals of the Carnegie Museum, **52:** 277–298.

Schweigger, E. 1964. El litoral Peruano. Universidad Nacional "Frederico Villarreal," Lima, Peru.

Smith, M. 1944. Panamic Marine Shells. Tropical Photographic Laboratory, Winter Park, Florida.

Soot-Ryen, T. 1955. A report on the family Mytilidae (Pelecypoda). Allan Hancock Pacific Expeditions. **20**(1): 1–154.

Sowerby, G. B. 1833. Characters of new species of Mollusca and Conchifera collected by Mr. Cuming. Proceedings of the Zoological Society of London for 1833, 82–85.

———. 1835. Characters of and observations on new genera and species of Mollusca and Conchifera collected by Mr. Cuming. Proceedings of the Zoological Society of London for 1834, 41–47.

Stothert, K. 1985. The Preceramic Las Vegas culture of coastal Ecuador. American Antiquity, **50:** 613–637.

Stuiver, M., and B. Becker. 1993. High-precision decadal calibration of the radiocarbon time scale, a.d. 1950–6000 b.c. Radiocarbon, **35**(1): 35–65.

Tattersall, I. 1985. The human skeletons from Huaca Prieta, with a note on exostoses of the external auditory meatus, pp. 60–64. *In* J. Bird and J. Hyslop, eds., The Preceramic Excavations at the Huaca Prieta Chicama Valley, Peru. Anthropological Papers, vol. 62, part 1. American Museum of Natural History, New York.

Tello, J. 1956. Arqueologia del Valle de Casma. Culturas: Chavin, Santa o Huaylas Yunga y Sub-Chimu. Vol. 1. Universidad Nacional Mayor de San Marcos, Lima.

Thompson, D. 1961. Architecture and Settlement Patterns in the Casma Valley, Peru. Ph.D. diss., Department of Anthropology, Harvard University, Cambridge, Massachusetts.

———. 1964. Formative Period architecture in the Casma Valley. Thirty-Fifth International Congress of Americanists, **1:** 205–212.

Wells, L. 1988. Holocene Fluvial and Shoreline History as a Function of Human and Geologic Factors in Arid Northern Peru. Ph.D. diss., Department of Geology, Stanford University, Stanford, Calif.

Wells, L., and J. Noller. 1997. Determining the early history of El Niño. Science, **276:** 966.

Wendt, W. 1976. El asentamiento Precerámico en Río Seco, Peru. Lecturas en Arqueología 3, translated by P. Kaulicke. Universidad Nacional Mayor de San Marcos, Lima, Peru.

Wise, K., N. Clark, and S. Williams. 1994. A Late Archaic period burial from the south-central Andean coast. Latin American Antiquity, **5:** 212–227.

5

The Impact of the El Niño Phenomenon on Prehistoric Chimú Irrigation Systems of the Peruvian Coast

Thomas Pozorski and Shelia Pozorski

Long-abandoned prehistoric irrigation systems are a common feature of the landscape in many Peruvian coastal valleys. Some of the most impressive examples of prehistoric irrigation systems can be found between the La Leche Valley and the Viru Valley on the north coast of Peru (Kosok 1965). These remains of canals and occasional fields, which currently lie outside the limits of modern irrigation, are believed to date to about 0 B.C./A.D. or later, within Early Intermediate Period (200 B.C.–A.D. 600) through Late Intermediate Period (A.D. 1000–1470) times. Studies of these exceptionally well-preserved remains of ancient land reclamation features reveal that their planners and builders faced a variety of challenges, including difficulties presented by local topography, the nature of the substrate, and periodic climatic variation, especially the notable impact created by strong El Niño rains that hit the Peruvian north coast a few times each century. Some challenges were effectively met through varied and often ingenious engineering feats. Other challenges were never successfully overcome despite the expenditure of vast amounts of labor. To ameliorate the effects of such engineering fiascos, alternative strategies were developed to compensate for production lost as a result of failed reclamation efforts.

The data and conclusions presented here are the result of fieldwork within the Moche and Chicama Valleys during the late 1970s by the Programa Riego Antiguo archaeological project. This project involved intensive survey and mapping of the prehistoric irrigation systems outside the limits of modern cultivation within the Moche Valley, as well as study of the area between the Moche and Chicama Valleys traversed by the Chicama–Moche Intervalley Canal. All of these areas with preserved prehistoric canals were explored further through excavations that transected the canal channels and by means of occasional horizontal clearing. The Moche and Chicama prehistoric irrigation systems had been subject to surface survey and limited test excavations prior to the Programa Riego Antiguo archaeological project (Farrington 1974, 1980; Farrington and Park 1978; Kosok 1965; Kus 1972). It was evident from the beginning of the project, however, that intensive excavation would be needed to sort out the complex nature of these systems and their relationships with the prehistoric sites in the area; the societies that built, maintained, repaired, and ultimately abandoned them; and the surrounding environment that was subjected to periodic El Niño rains. Through detailed study of the surface evidence and excavated canal profiles and features, it was possible to develop a detailed chronology of the growth and decline of the irrigations systems, including when and how they were affected by El Niño rain.

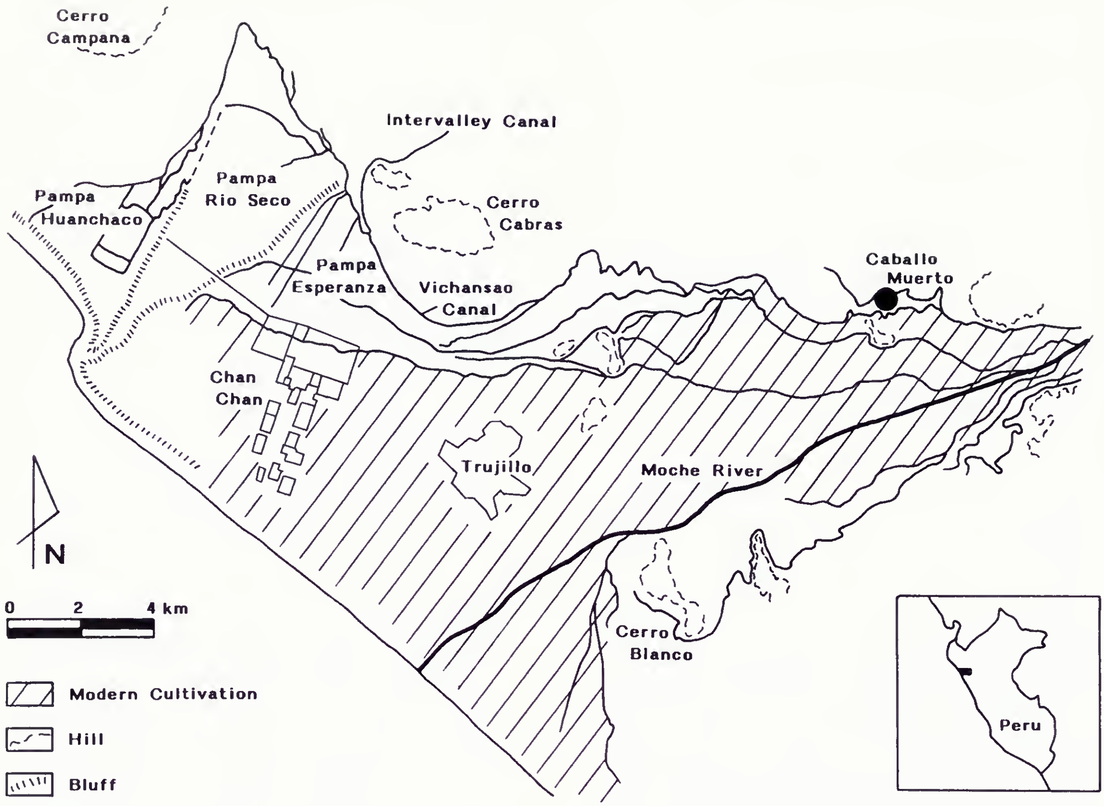

Figure 1. Map of the Moche Valley showing the extent of modern cultivation, the Three-Pampa area, prehistoric canals outside of modern cultivation, and relevant archaeological sites.

The Archaeological Evidence

Canals and Fields

The extremely arid climate of coastal Peru fosters excellent preservation of archaeological remains, including the prehistoric agricultural features that extend beyond the limits of modern cultivation (Figs. 1 and 2). These range from major and minor canals to fields with intact furrows (Fig. 3). Within the Moche Valley, several small prehistoric canal systems are preserved on both sides of the river; however, the greatest expanse of preserved canals and fields lies well down-valley, toward the ocean. This latter zone, which contains Pampas Esperanza, Rio Seco, and Huanchaco, has been designated the Three-Pampa area (Figs. 1 and 2). In late prehistoric times, an effort was made to draw water into the Three-Pampa portion of the system from the Chicama River in the next valley north via the unsuccessful Chicama–Moche Intervalley Canal. This tremendous undertaking is well documented in the archaeological remains (Kosok 1965:90–94; T. Pozorski 1987; T. Pozorski and S. Pozorski 1982).

Within the Moche Valley, the largest canals in the archaeological record actually represent now-abandoned extensions of canals still in use along much of their lengths. These canals were designed for water transport; they drew water directly from the Moche River. A hierarchical system of increasingly smaller canals carried water from each major canal to associated sets of fields.

Excavations that transected canals and fields revealed the history of their construction and use or lack of use. As expected, major canals contained a succession of numerous channels, reflecting their permanence upon the landscape and long-term use. Successively smaller canals, and especially fields, contain correspondingly fewer distinct channels, reflecting the fact that smaller elements of the total system were more ephemeral. When the profiles of transected canals were examined, individual channels could

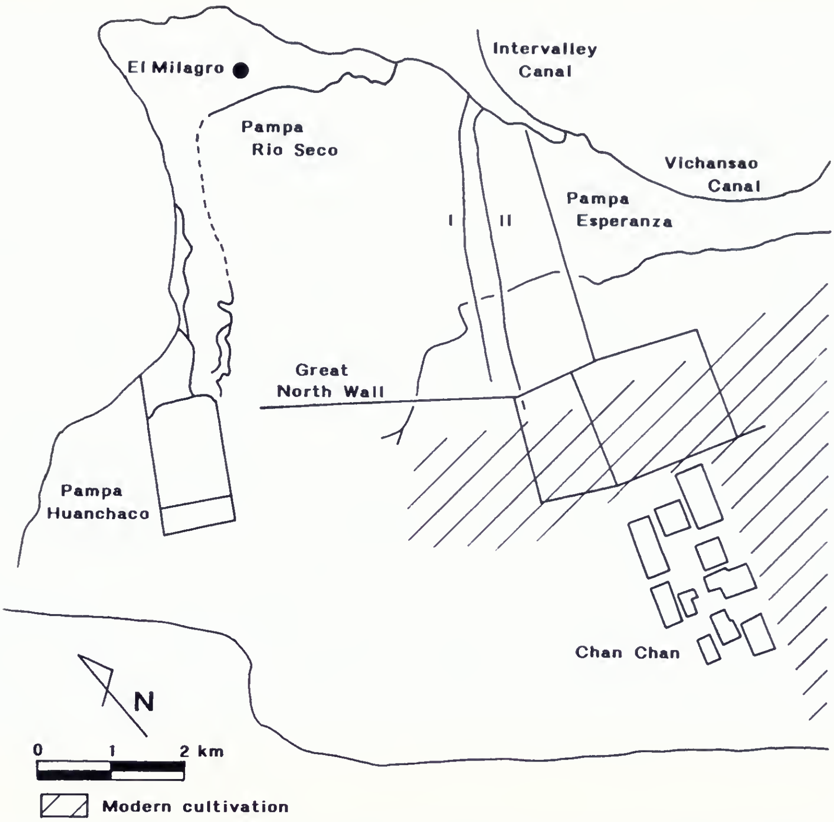

Figure 2. Map of the Three-Pampa area showing the major irrigation canals that lie north of Chan Chan.

be distinguished by the nature of their component sediments; and these channels—or major use episodes—could be traced from profile to profile along the length of major canals and many minor canals. Based on these connections among canal channels, it was possible to develop a sequence for the construction and use of the portion of the prehistoric Moche Valley canal system outside modern cultivation.

Evidence of Canal Use

Profiles of transected canals also yielded information on the duration and intensity of canal use. Canal use was reflected archaeologically mainly in two ways. First, within the active channel, laminar sediments were formed as water-borne material left in suspension or surface deposits blew in and were arranged in a laminar configuration by the water flow (Fig. 4). Frequently, this deposition constituted the process by which the initially excavated channel stabilized in response to water flow. Subsequent changes in water velocity or quantity resulted in erosion and/or deposition.

A second indicator of canal use was the dark coloration of sediments or soils beneath a channel that resulted from water logging. When sediments are subjected to repeated wet-dry episodes, oxidation occurs, turning the surfaces of the individual soil particles first yellow to orange and ultimately brown to dark red. Canals observed in profile exhibited varying degrees of oxidation from very slight to no discoloration to intensive darkening 40 cm or more below the active channel. When sediments are kept wet for longer periods of time, waterlogging occurs, turning soil particles gray to black in color.

Neither an evaluation of the deposition and erosion of water-lain canal sediments nor a consideration of the amount of associated oxidation can be used to reconstruct absolute time spans for canal use. However, when taken together, they provide a relative indicator of the magnitude of use for a given channel. Based on the

Figure 3. View of stone-lined Chimú canals along the east edge of Pampa Rio Seco.

same evidence, canals or channels lacking both laminar sediments and oxidation never functioned effectively. Such abortive canal segments often have additional characteristics that precluded their effective use, such as an uphill slope (T. Pozorski and S. Pozorski 1982).

Irrigation Systems Prior to 0 B.C./A.D.

Preserved remains of prehistoric irrigation systems date relatively late in the Andean sequence; however, there is general agreement that irrigation agriculture had its beginning much earlier. Most authors (Burger 1992:57; Morris and von Hagen 1993:45; Moseley 1992: 126; Patterson 1985:67; S. Pozorski and T. Pozorski 1987:114; Richardson 1994:64; von Hagen and Morris 1998:46) date the inception of large-scale irrigation agriculture within Peruvian valleys to the Initial Period (2150–1000 B.C.). (Dating is based on calibrated radiocarbon dates using values supplied in Stuiver and Becker [1993].) Experimentation likely occurred even earlier, during the Late Preceramic (3000–2150 B.C.), when most of the population was concentrated in large settlements near the coast. Small, short canals may have been constructed within or near the active flood plains, which are a considerable distance from most Late Preceramic sites. Such experimentation with water control is suggested by the varied inventory of cultivated species at Late Preceramic sites. These include squash, common bean, potato, avocado, lima bean, *lucuma,* guava, *cansaboca,* and especially gourd and cotton—industrial plants essential to the lives of coastal fishermen (S. Pozorski 1987:16; S. Pozorski and T. Pozorski 1987:113, 1988:95–96; T. Pozorski and S. Pozorski 1990:17–18).

Evidence for Initial Period irrigation is more substantial. At this time large, complex sites dominated by one or more platform mounds appear well inland in over 15 river valleys of the north and central Peruvian coast. These mounds are located at or near optimum zones for canal intakes as if to effectively monitor or control water use (Burger 1992:57; Morris and von Ha-

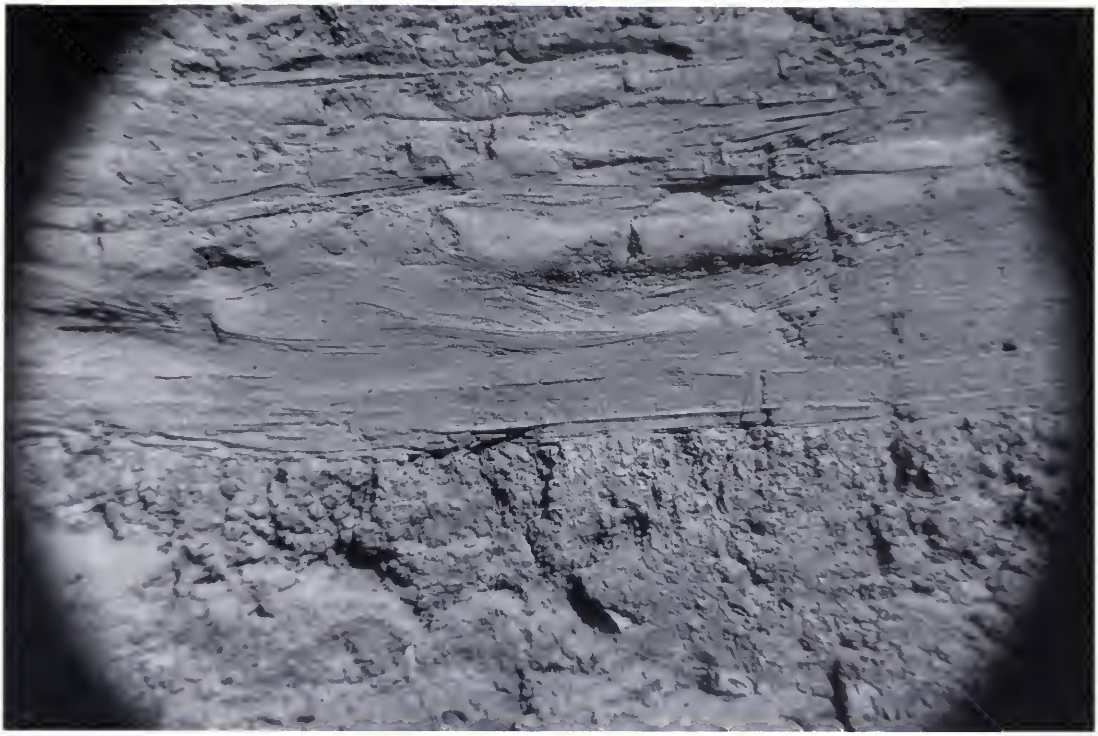

Figure 4. View of laminar deposits within a now-abandoned prehistoric Chimú canal.

gen 1993:45; Moseley 1992:126; Patterson 1985:67; S. Pozorski and T. Pozorski 1987:114; T. Pozorski 1982; Richardson 1994:64; von Hagen and Morris 1998:40). In the Moche Valley during the Initial Period, the irrigation system probably extended down to the Caballo Muerto Complex (Fig. 1). Many of the large mounds at these sites also face up-valley or upriver, an orientation that has been correlated with reverence for the source of the river water so essential to irrigation (S. Pozorski and T. Pozorski 1987: 114; Williams 1985:230). Subsistence data available for this time period document a marked increase in the variety and especially the quantity of cultivated plants consumed and used at Initial Period sites. Peanuts and manioc are some of the food plants added to the prehistoric diet at this time. Comparisons of subsistence inventories for coastal and inland sites suggest that marine resources continued to be important and that satellites of the inland centers were established and maintained on the coast to supply essential protein in exchange for agricultural products (S. Pozorski and T. Pozorski 1979, 1987:19–20).

Early Intermediate Period Irrigation Systems Within the Moche Valley

Within the Moche Valley, the earliest evidence of prehistoric irrigation that expanded beyond the limits of modern cultivation dates to the Early Intermediate Period and is associated with the Moche occupation of the valley. At this time, the extent of cultivated land extended slightly outside modern limits, encompassing only Pampa Esperanza and a narrow strip within Pampa Rio Seco along the west edge of Pampa Esperanza (Figs. 5 and 6). With the exception of a single canal on Pampa Rio Seco that lies near the modern surface, the Moche canals are deeply buried, directly underlying subsequent Chimú use of the same channels.

The Moche and Chimú efforts to reclaim the area are distinct, however, and can be distinguished on the basis of several lines of evidence. Canal channels believed to have been constructed during the Early Intermediate Period are often directly associated with Moche sites, and their extent corresponds to the extent

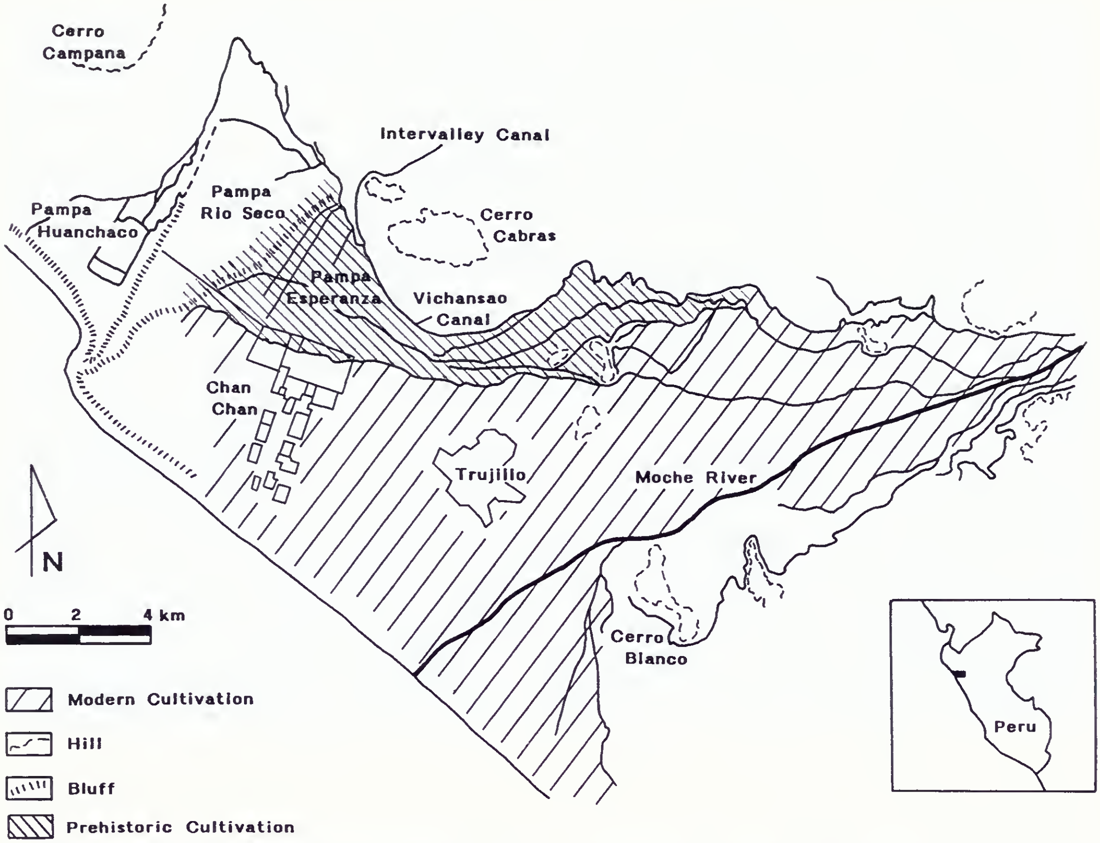

Figure 5. Map of the Moche Valley showing the extent of prehistoric irrigation outside modern cultivation during Moche times (A.D. 100–600).

of substantial Moche occupation of the Three-Pampa area. Canal-bank sediments associated with these deep channels contained occasional Moche ceramics, but no later cultural material, and one charcoal sample from a canal bank yielded a radiocarbon date of A.D. 550 ± 80 (T. Pozorski 1987:Table 1). Finally, the natural substrate beneath these canals is the most intensively oxidized, characterized by dark red coloration, and waterlogged, characterized by near black coloration.

Late Intermediate Period Irrigation Systems Within the Moche Valley

Irrigation agriculture within the Moche Valley reached its maximum extent during the occupation of the valley by people known as the Chimú (Fig. 7). This state, governed from Chan Chan—its capital located within the Moche Valley—dominated the north coast during the Late Intermediate Period. The beginnings of this state date to about A.D. 900. By about A.D. 1300, the Chimú state had expanded north and south to incorporate lands between the Jequetepeque and Casma Valleys, thereby dominating the area previously governed by the Moche state (Donnan 1978:1; Mackey and Klymyshyn 1990:203–205; T. Topic 1990:184–189). This was apparently also the time of maximum agricultural expansion—the time when the Chimú implemented an aggressive program of canal and field expansion within valleys under their control. Motivated by an El Niño flood that adversely impacted their land reclamation efforts, the Chimú altered their strategy and expanded their polity much further north and south to en-

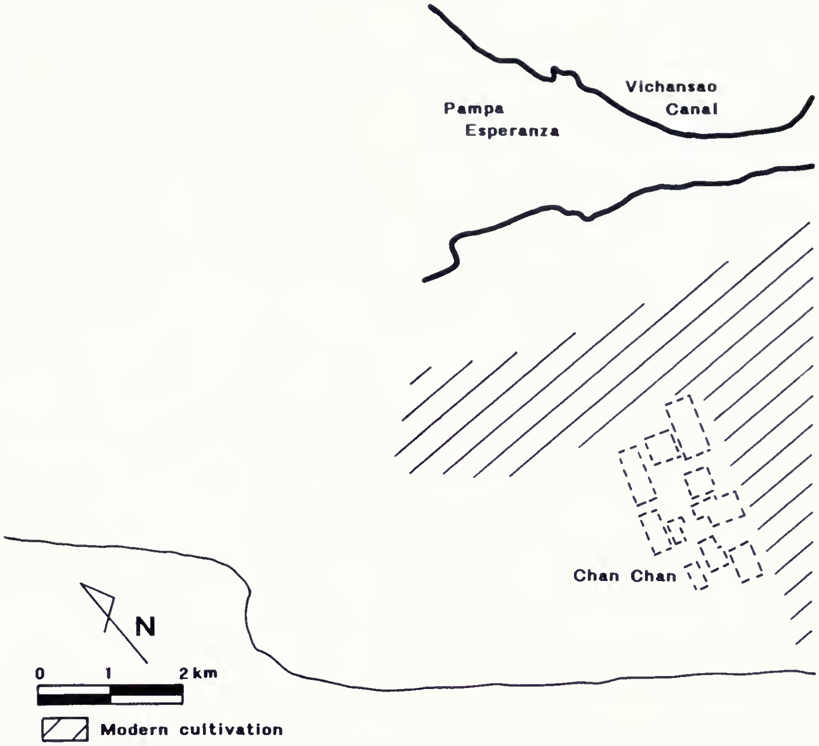

Figure 6. Map of the Three-Pampa area showing the major canals which functioned during Moche times (A.D. 100–600).

compass lands as far north as Tumbes and as far south as the Chillon Valley (Donnan 1990: 267; Mackey 1987:121–122; Richardson et al. 1990:434–436; Rowe 1948; Shimada 1990: 313). Domination by the Chimú state ended in A.D. 1470 as a result of defeat by the expanding Inca empire.

Early Intermediate Period Moche canals underlie some of the major channels that were subsequently used by the Chimú; however, virtually all of the prehistoric irrigation features readily visible on the surface were originally constructed by the Chimú. These include small systems located well inland on either side of the valley as well as the Three-Pampa area—an unusually large zone of ancient canals and fields that extends from the edge of modern cultivation toward the ocean (Figs. 1 and 2). The Chimú were also responsible for the conception and execution of the Chicama–Moche Intervalley Canal, a massive undertaking to divert water from the Chicama River 20 km to the north and channel it onto the Three-Pampa area (Kus 1972; Ortloff et al. 1982; T. Pozorski 1987:116; T. Pozorski and S. Pozorski 1982). The Three-Pampa area, which consists of Pampa Esperanza, Pampa Rio Seco, and Pampa Huanchaco, is an integrated system of canals and fields originally fed by two major canals on the north side of the Moche River. The Three-Pampa area as well as the Intervalley Canal that was intended to supplement the water supply for the Three-Pampa area are the main focus of this study.

The Administration of Land Reclamation

In order to execute tasks as formidable as cultivation of the Three-Pampa area and construction of the Chicama–Moche Intervalley Canal, the Chimú built rural administrative centers (Keatinge 1974, 1980; Keatinge and Day 1973, 1974; T. Pozorski 1987:114–117). Although these sites also likely served to monitor maintenance of the irrigation systems as well as production within the fields, they were primarily established to oversee initial canal and field construction. In

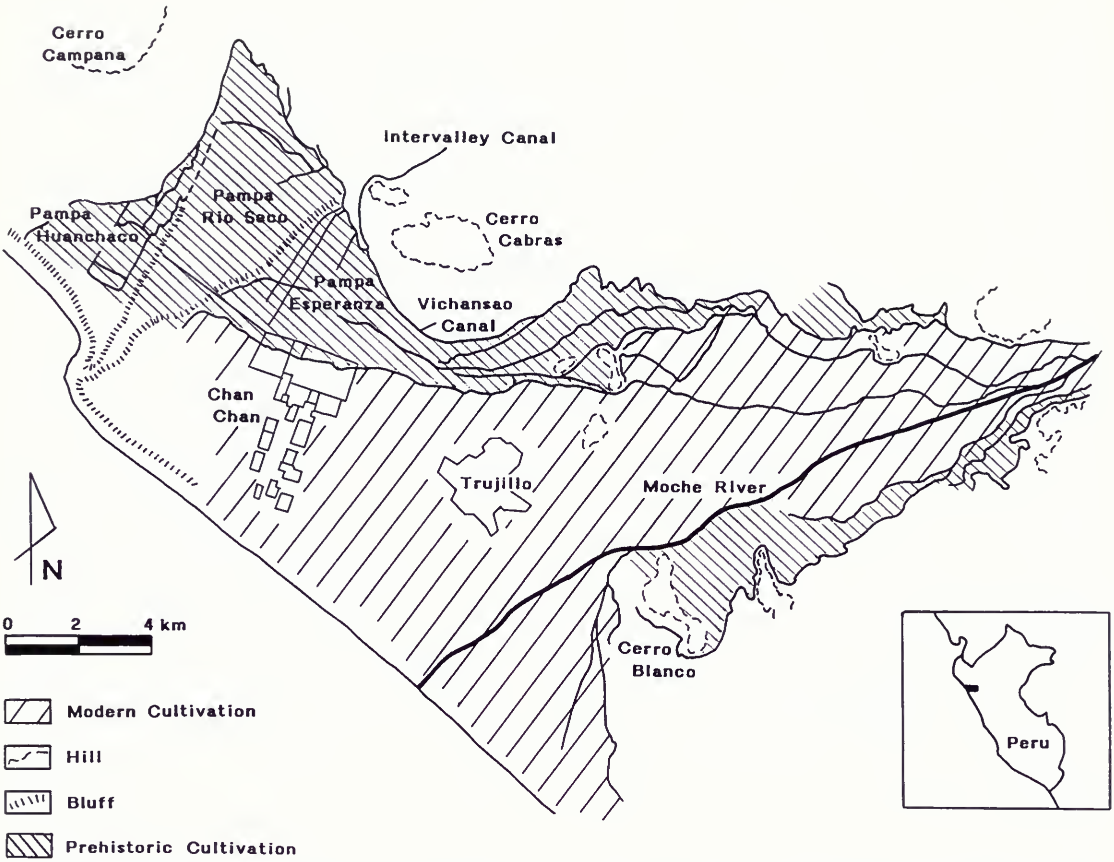

Figure 7. Map of the Moche Valley showing the extent of prehistoric irrigation outside of modern cultivation during Chimú times (A.D. 1000–1300).

this capacity, the rural administrative centers represent expansion of the Chimú state onto previously unfarmed desert areas, and they are consistently located in close association with canals and field systems (T. Pozorski 1987:114–117). Ironically, many of the canals and field systems connected with rural administrative centers were never fully operational.

Within the Moche–Chicama Valley area, four rural administrative centers have been identified and investigated to date. These centers are Quebrada Katuay, located well inland on the north side of the Moche Valley; El Milagro de San Jose, located on Pampa Rio Seco (Fig. 2); Quebrada del Oso, located some 3 km south of modern cultivation in the Chicama Valley and associated with the Chicama–Moche Intervalley Canal; and Pampa Mocan, located 3.7 km north of modern cultivation in the Chicama Valley (Keatinge 1974; Kus 1972:99–102; T. Pozorski 1987:Fig. 1).

Challenges, Successes, Failures, and Alternative Strategies

The Chimú faced distinct challenges as they expanded the Moche Valley irrigation system far beyond its previous limits, and especially as they endeavored to draw water from the Chicama River into the Moche system. These challenges are directly related to the fact that, once the Chimú moved beyond land reclaimed in Moche times, they were expanding the irrigation system into areas not previously cultivated. The topography, the nature of the local substrate, and the lack of adequate water were for-

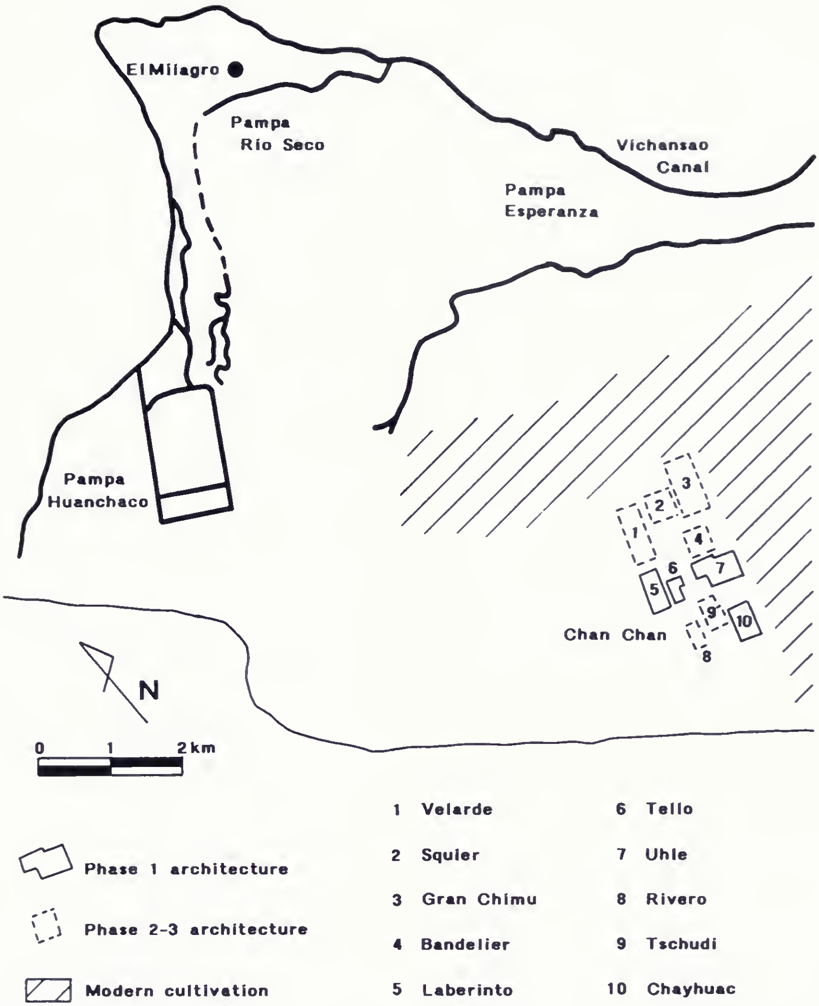

Figure 8. Map of the Three-Pampa area showing the maximum extent of canal systems during preflood Chimú times (A.D. 1000–1300).

midable obstacles. Once in place, prehistoric irrigation systems were also impacted periodically by El Niño-related rainfall.

Topography

Paramount in the effort to fully reclaim the Three-Pampa area was the extension of the Vichansao Canal, the major canal that drew water from the Moche River, so that water could be transported to Pampas Rio Seco and Huanchaco (Figs. 7 and 8). In doing this, the objective was to incorporate the maximum amount of land while also creating a functioning canal to provide water for this land. The projected route was along the north edge of Pampa Esperanza, then across Pampa Rio Seco—a dry river channel, all the while maintaining sufficient elevation to provide water to Pampa Huanchaco, an area of higher ground on the other side of Pampa Rio Seco. The Chimú ran the Vichansao as high as possible along the valley edge, creating a channel with a remarkably shallow slope of .0001. As the canal crossed Pampa Rio Seco, the channel bottom ran at approximately the surface level of the pampa for much of its length. This was accomplished by building up banks using soil scraped from the nearby surface to create a channel at ground level, but without any elevation of the canal bottom. Further along, to cross lower portions of Pampa

Rio Seco and maintain elevation sufficient to supply Pampa Huanchaco with water, a true aqueduct was constructed, raising both the channel and banks above ground level.

Where the Vichansao was excavated into the substrate or ran at ground level, occasional abortive channels that take off "uphill" attest to the difficulty of the builders' task, and also suggest that Chimú engineering efforts were characterized by trial and error. Nevertheless, the Chimú were able to create a functioning canal that traversed varied terrain while maintaining an extremely low slope in order to maximize the amount of land reclaimed. The Vichansao, and lesser canals within the Three-Pampa system, were functioning canals, as indicated by laminar sediments and especially oxidation. Although the degree of oxidation decreases toward the periphery of the system, there is clear evidence of functioning canals all the way out to Pampa Huanchaco. This is ample testimony to the success of Chimú efforts to extend the Moche Valley irrigation system far beyond any previous limits.

Natural Substrate

In constructing the Vichansao canal, much of the canal's channel was cut through a zone of aeolian sand banked against Cerro Cabras. Sand-filled channels attest to problems with local sand blowing into the canal, and ample sand in bank deposits documents successful efforts to keep the channel open through regular cleaning. Such porous sand would also have allowed much water loss through seepage until sufficient finer particles—silts and sands—had accumulated to self-line the channel. There was little effort to artificially line the channel as a means of retarding seepage. Stone lining and, rarely, adobe lining on the canal interiors was regularly employed where the Vichansao crossed Pampas Rio Seco and Huanchaco. However, the channel bottom was not lined, and sidewall lining apparently functioned more to retain loose bank soils than to prevent seepage.

The same problems of substrate porosity and blowing surface sand also impacted smaller feeder canals and fields on the Three-Pampa area. On Pampa Esperanza, which had been under cultivation since the Early Intermediate Period, field soils were silt-rich and less porous near the surface, allowing for better moisture retention. On the other two pampas, especially Rio Seco, the substrate was very loose, consisting of porous, coarse sand to gravel and cobbles. Ironically, although such soils make farming the surface difficult at first because so much water is lost through evaporation and seepage, they also provide near-ideal conditions for drainage beneath the fields and canals. This prevents the buildup of salts that can potentially render fields useless.

Chicama–Moche Intervalley Canal

The Chicama–Moche Intervalley Canal ranks among the most ambitious irrigation projects ever attempted on the north coast. It represented an effort to bring water from the Chicama River across the 70-km-long canal route of rocky, uneven desert to the Moche Valley (Fig. 9; T. Pozorski and S. Pozorski 1982:Fig. 1). Although a few small areas of fields were laid out or constructed along its course between the two valleys, the Chicama–Moche Intervalley Canal was apparently conceived of primarily as a means to increase the amount of water available for the Three-Pampa area within the Moche Valley. Unfortunately, it also proved to be among the most noteworthy engineering fiascos ever documented archaeologically.

Evidence of oxidized sediments within the main supply canal, the Vichansao, all the way to Pampa Huanchaco reveals that the Chimú had created a canal that was sufficiently well engineered to reach the farthest limits of the land they endeavored to bring under cultivation. Nevertheless, the magnitude of oxidation within the channel decreases markedly along its route toward the periphery. This suggests that there was rarely sufficient water to keep the farthest reaches of the system under cultivation. To remedy this, about A.D. 1100 the Chimú embarked on a labor-intensive effort to supplement the Vichansao's flow and provide additional water to the entire Three-Pampa area. Evidence of this intent comes from the fact that the Chicama–Moche Intervalley Canal path circles well around the base of Cerro Cabras in order to feed into the Vichansao at a point sufficiently upstream to allow access to Pampa Huanchaco (Figs. 7 and 9). The system of smaller canals (Fig. 9, Canals I and II) taking water from the Vichansao to the fields was also redesigned at

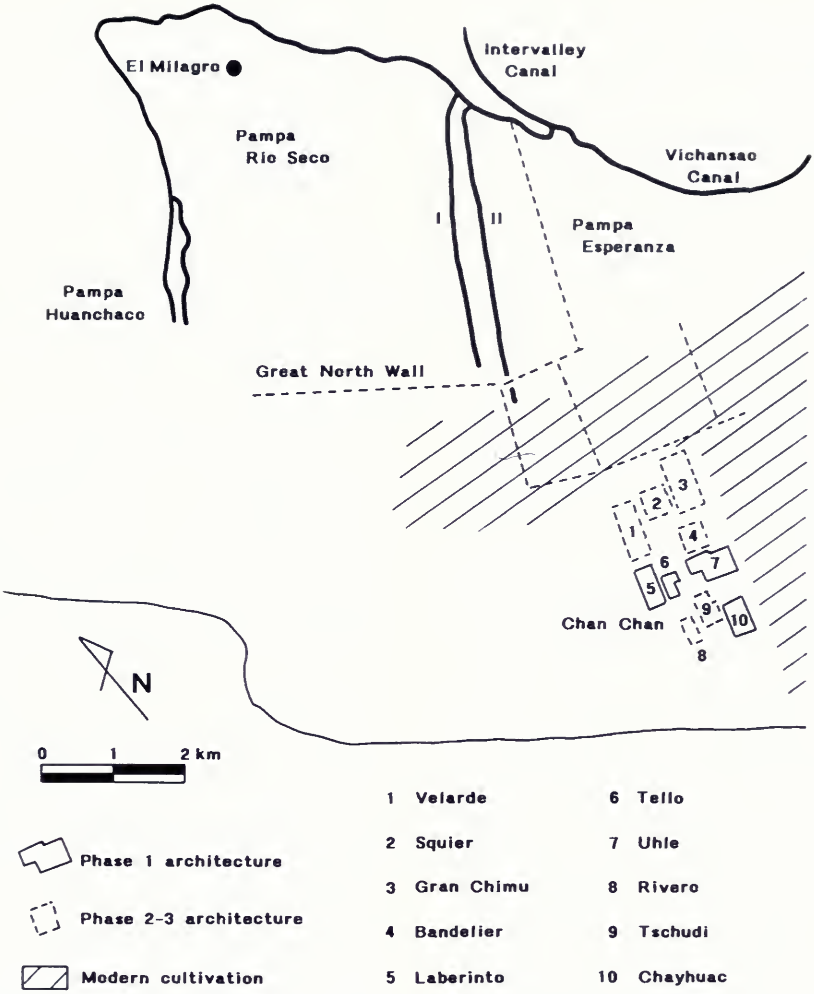

Figure 9. Map of the Three-Pampa area showing the reconfiguration of the Moche Valley canal system in anticipation of supplemental water from construction of the Chicama–Moche Intervalley Canal. The relationship of the Great North Wall and Phase 2–3 architecture of Chan Chan to Canal II is also indicated.

about the same time in anticipation of the additional water.

Much effort was expended on the Chicama–Moche Intervalley Canal before it was finally abandoned. At least one channel—which in places is quite shallow—can be traced across its entire intended route. The greatest elaboration, however, is evident in the portion of the canal north of the "divide"—the highest point topographically which the canal had to traverse along its route between the Chicama and Moche Valleys. This northern zone is an engineer's nightmare because of the uneven terrain, a seemingly unending series of *quebradas* and rocky ridges descending from the Andean foothills. When their first effort to create a functioning canal failed, the Chimú tried again and again, raising the channel each time in the hope of attaining sufficient elevation to cross the divide. This required tremendous effort, especially where the canal had to be supported against bare bedrock. At several locations the Chimú used fire to heat crack the stone, and then cut through the bedrock of ridges that impeded the canal's progress. Charcoal from these fires provided samples for radiocarbon dating (T. Pozorski 1987:113, Table 1). Some segments of the canal were rebuilt as many as seven times, with each successive segment requiring additional stone-lined terraces to shore up the downslope bank and support the channel.

Numerous excavations transecting the Chicama–Moche Intervalley Canal channel were made north of the divide in the vicinity of Quebrada de Oso. This location was selected because canal construction was especially elaborate there and a sizable expanse of fields and smaller canals was also present. An exceptionally large and long aqueduct had also been constructed in this area, across Quebrada del Oso. This aqueduct was largely destroyed by El Niño-related wash down the *quebrada*; however, this same El Niño destruction exposed a cross section of the aqueduct that was cleaned as part of the excavations of the Chicama–Moche Intervalley Canal.

Despite claims of great Chimú engineering skills (Kus 1972, 1984; Moseley 1992:260; Ortloff 1981, 1988, 1993, 1995; Ortloff et al. 1982, 1985), numerous excavations within the Chicama–Moche Intervalley Canal yielded no evidence that the canal had ever effectively carried water (T. Pozorski 1987:116; T. Pozorski and S. Pozorski 1982). Most significantly, there was no evidence of oxidation in any of the channels. Cuts transecting the canal occasionally revealed bands of fine sand and silt; however, these lacked the laminar structure of moving water. These deposits are clearly the result of standing water that periodically filled segments of the channels during El Niño rains. Capture of standing water within segments of the channel was facilitated by the undulating slope of the canal that resulted from engineering error.

Smaller canals constructed to water the area of fields near Quebrada del Oso likewise show no evidence of use. Their construction is interesting, however, because their intakes and channels were cut into the bedrock of ridges that projected toward the fields. Where these ridges ended, soils were mounded up to aqueduct the channels into the fields. During the latest effort to rebuild the canal, the intakes for these canals were filled in, becoming part of the canal bank. This ended all efforts to cultivate fields along the Chicama–Moche Intervalley Canal route.

The entire 70-km length of the Chicama–Moche Intervalley Canal was surveyed on foot as well as mapped, and slope measurements were made with a 1-second theodolite. Problems that Chimú engineers experienced in their efforts to traverse the difficult terrain became readily apparent during this careful study of the canal. They clearly lacked the ability to topographically relate the elevation of the intake for the Chicama–Moche Intervalley Canal within the Chicama Valley to the elevation of the divide—the highest point the canal would traverse. The result was a disastrously blind following of topography "up and down" as the channel ascended and then descended *quebradas*. The channel was also cut considerably uphill across seemingly flat, but actually ascending, surfaces. Among the most notable examples of such engineering flaws is a 13.8-km segment just south of Quebada del Oso where the canal slope goes *uphill* almost 70 m (T. Pozorski and S. Pozorski 1982:854–860). It would seem that once the Chimú engineers left the Chicama Valley proper, where they had used the cultivated valley bottom and the river as their frames of reference, they were unable to lay out a functioning canal with a downhill slope.

Impact of the El Niño of ca. A.D. 1300–1350

In approximately A.D. 1300–1350, an exceptionally strong El Niño event impacted the Peruvian north coast. The effect on the Moche Valley irrigation system was considerable. Canal intakes along the river would likely have been washed out, rendering canals inoperable until repairs could be made. Damage to canals was variable. In situations where El Niño wash descended a hillside onto sandy pampa, small canals were frequently totally washed away, covered over, or filled in as the pampa sediments were rearranged by the action of the swiftly moving water (Fig. 10). Canals and aqueducts crossing *quebradas* were cut, and substantial segments were washed away by water flowing perpendicular to the canal course. In cases where floodwater flow paralleled the canal channel, additional water frequently entered the channel. Flood water flowing within canals that had initially been excavated into sandy substrate caused considerable damage, often cutting through the canal bottom and gouging out a much deeper channel (Fig. 11). Floodgate flowing within canals initially excavated into rocky substrate caused less damage. Finer silt and sand particles were washed from around larger stones that came in contact with the

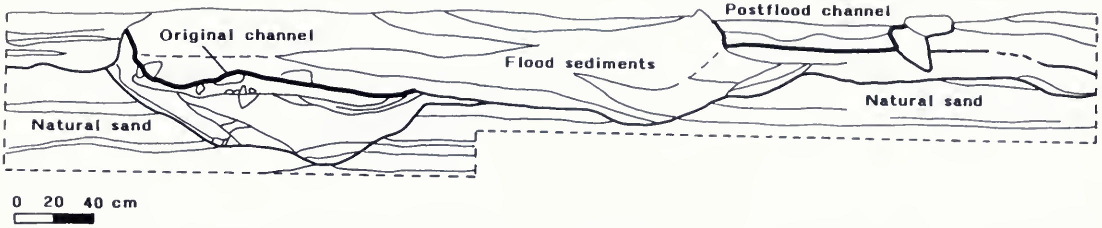

Figure 10. Profile of a small north-south feeder canal parallel to and east of Canal II in a sandy area on Pampa Esperanza. On the left are the remnants of the original channel, partially collapsed and then buried by El Niño wash that hit the canal laterally. On the right is a reconstructed post-flood channel built over the flood sediments. This second channel was never a functioning canal.

floodgate, and the surfaces of the stones were scoured to a blue-gray color.

Such extensive damage made irrigation of the Three-Pampa area impossible until repairs could be made. Some efforts to reactivate the system are readily evident in the archaeological record. Where canals had been totally washed away or obscured, new channels were built (Fig. 10). Gouged-out segments were infilled to approximately restore original slope (Fig. 11). Segments of canals cut by perpendicularly flowing water were also rebuilt. At times this involved rerouting the channel above and around the break to maintain the downhill slope within a flood-enlarged gully or *quebrada.*

Instances where transverse cuts were repaired were particularly instructive regarding the magnitude of the El Niño event of ca. A.D. 1300–1350. Characterization of this event as unusually severe reflects evidence from canal reconstruction suggesting that no subsequent El Niño had comparable impact. Survey data from the Three-Pampa area reveal that sizable segments of some canals were washed out. Some new channels were built by the Chimú to reconstruct canals at these locations. These new channels are distinct from the earlier canal construction, and have not been affected by later El Niño activity. Other new channels have been transected by subsequent washes. None of the subsequent damage, however, comes close in magnitude to the swath cut by the A.D. 1300–1350 El Niño wash (see below, however, for a cautionary note on this interpretation).

Within the Three-Pampa area, efforts to repair the irrigation system were extensive; however, excavation within these channels revealed that the reconstructed system was never effectively used. Laminar sediments within channels are minimal, and there is no evidence of the associated oxidation indicative of significant wetting and drying. Most channels pertaining to this latest reconstruction are also considerably smaller than preceding uses of the canal. These

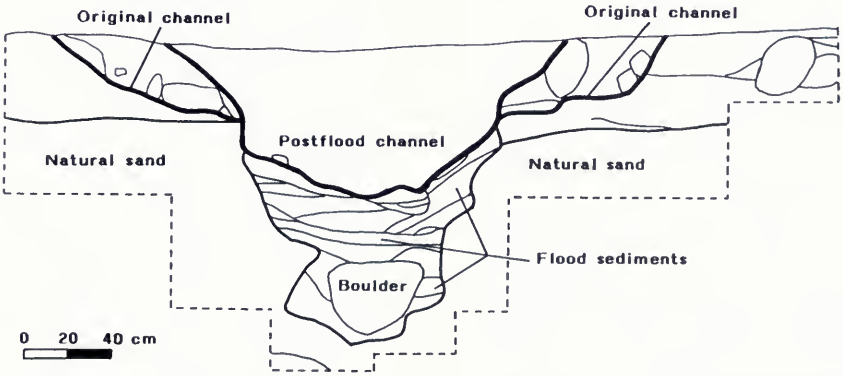

Figure 11. Profile of Canal II near its north end. The original channel was a functional canal showing signs of laminar deposits and oxidation. Then the center of this channel was gouged out by swiftly flowing El Niño wash off Cerro Cabras that flowed down the route of Canal II. Water flowed around a large boulder, and then, as the flow subsided, sediment was deposited. Finally, a reconstructed post-flood channel, which was never functional, was built above the flood-deepened channel and its deposits.

less substantial, unused canals represent the final, unsuccessful effort to irrigate the Three-Pampa area. Clearly, reclamation of the Three-Pampa area was no longer a priority for the Chimú.

Despite efforts to reconstruct the system, the Three-Pampa area was never effectively brought back under cultivation after the A.D. 1300–1350 El Niño. The timing of this disaster also coincides with the latest dates for the Chicama–Moche Intervalley Canal, indicating that its construction was halted at the same time. The devastating effects of El Niño appear to have been a catalyst that motivated the Chimú to abandon both their unsuccessful efforts to bring Chicama water to Moche canals and fields as well as their previously successful efforts to reclaim the relatively marginal Three-Pampa area which the Chicama–Moche Intervalley Canal was supposed to have helped irrigate. Possibly to compensate for production lost due to abandonment of the Three-Pampa area and for labor wasted on the Intervalley Canal, the Chimú changed their strategy and began to look outside the Moche Valley for support.

Alternative Strategies

The sequence for canal construction and use on the Three-Pampa area can be correlated with the construction sequence for the compounds at the Chimú capital of Chan Chan, immediately south of Pampa Esperanza (Figs. 1 and 9). Generally, investigators agree that these compounds served as palaces for the rulers of the Chimú empire (Day 1980, 1982; Klymyshyn 1982; Kolata 1982). Although there is disagreement about the exact order of construction of the compounds (Klymyshyn 1987:101–102; Kolata 1990; Topic and Moseley 1983:158–162), a general three-phase construction has been developed by Kolata (1982) based on the shape of adobe bricks used to build the major compound walls. Of the ten monumental compounds, four (Chayhuac, Uhle, Tello, and Laberinto) make up Phase 1. Phase 2 consists of the Gran Chimú compound and various associated walls to the north of that compound, including the Great North Wall that bounds the south side of Pampa Esperanza (Fig. 9). Phase 3 consists of the five remaining compounds (Squier, Velarde, Bandelier, Tschudi, and Rivero). Since the publication of Kolata's original sequence, many other investigators, including Kolata himself, have proposed more detailed construction sequences based on analyses of architectural elements within the compounds such as *audencia* shape, burial platform configuration, and entry courts, as well as associated ceramics (Klymyshyn 1987:101–102; Kolata 1990; Topic and Moseley 1983:158–162). All of these sequences, however, represent only minor variations on Kolata's original 1982 sequence and have little bearing on the overall relationship between the monumental compounds and the Three-Pampa irrigation area. Therefore, for the purposes of this discussion, we will follow the original Kolata sequence.

During the construction of the Phase 1 Chan Chan compounds, when the site was in its earlier stages of growth, the irrigation system reached its maximum extent. Effecting their agricultural expansionist policies through rural administrative centers, the Chimú attempted to reclaim inland areas on both sides of the valley, incorporated the entire Three-Pampa area, undertook construction of the Chicama–Moche Intervalley Canal, and expanded Chicama Valley irrigation systems beyond modern limits. Archaeological data indicate that use of the expanded Moche Valley irrigation system was abruptly interrupted between A.D. 1300 and 1350 by a devastating El Niño event. Despite efforts to reconstruct the system, reclamation of the more marginal zones of the Moche Valley agricultural system was effectively curtailed at about this time, and work on the Chicama–Moche Intervalley canal also ceased. The same El Niño event likely caused similar damage in other north and north-central coast valleys.

Chan Chan, however, continued to develop after the flood. Five compounds (Phases 2 and 3), comprising about half the area of Chan Chan, were built after the irrigation system had shrunk to approximately its modern limits. The key to this dating is the relationship between Canal II on Pampa Esperanza and the Great North Wall which is part of the Phase 2 construction at Chan Chan (Figs. 9 and 12). Canal II, which was part of the reworking of the Three-Pampa irrigation system in anticipation of water from the Intervalley Canal, is one of the latest canals to be built on Pampa Esperanza (Fig. 9). This canal contains sediment and oxidation associated with its original use plus deposits associated with the A.D. 1300–1350 flood within its channel (Fig. 12). The Great North

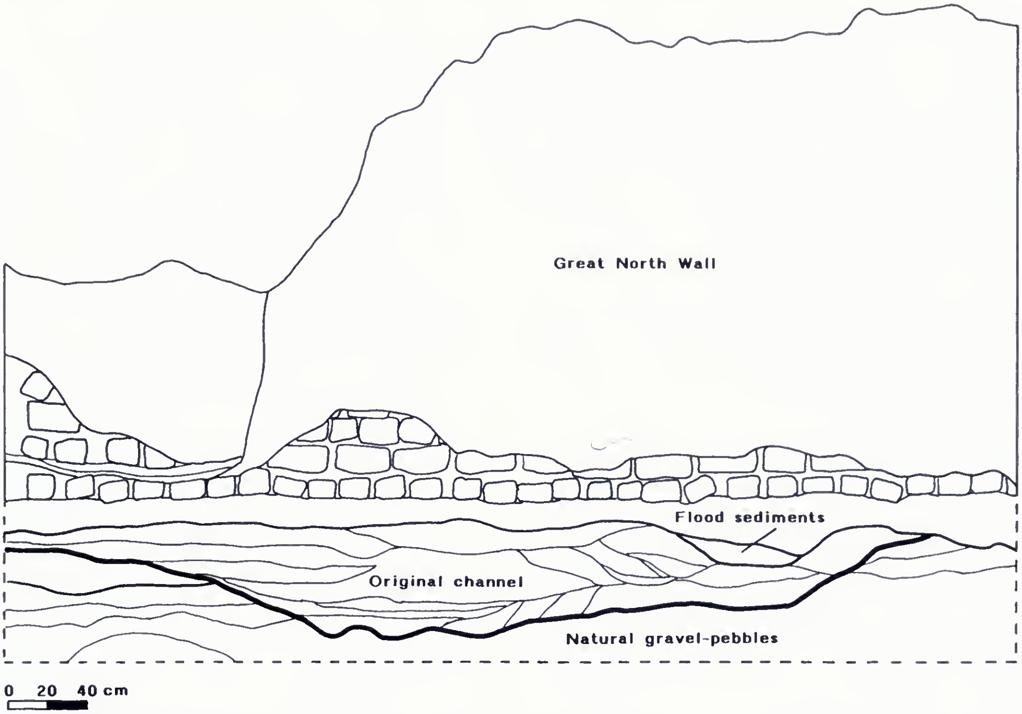

Figure 12. Profile of Canal II near its south end. The original channel was a functional canal complete with laminar deposits and oxidation. Subsequently the El Niño wash entered the channel, scouring out a small depression and leaving flood-borne deposits. Finally, a major east-west segment of the Great North Wall of Chan Chan, here composed primarily of adobe, was constructed over both the original channel and the flood sediments within this portion of the Canal II.

Wall, which is part of the Phase II construction of Chan Chan, was clearly built *over* Canal II. Thus, at least one-half of the visible compounds at Chan Chan postdate the time when the Three-Pampa area was most effectively irrigated. The minor, and largely unsuccessful, efforts at canal reconstruction on the Three-Pampa area after the A.D. 1300–1350 flood could partially overlap with the building and use of the Phase 2 architecture of Chan Chan, but are unlikely to date any later.

The devastating El Niño flood that curtailed reclamation efforts was likely a key factor in changing Chimú strategy. Rather than expending excessive labor to maintain fields in marginal lands, the Chimú apparently formed additional military units and set out to expand their domain into more northern and southern lands from which tribute could be extracted. Strategically, this was an optimum time to take advantage of rival polities that had been weakened by the El Niño disaster, especially farther north, where the impact was likely more severe. This second, more far-reaching phase of Chimú expansion was likely motivated not so much by the desire for agricultural products as by the desire to gain access to and control over the production of artisan goods, especially the metalworking that had been so successfully controlled from the Lambayeque area (Shimada 1982:178–179; T. Topic 1990). Within the ca. 150-year span between the flood of A.D. 1300–1350 and their defeat by the Inca, the Chimú quadrupled the area they controlled.

This example from the Moche Valley and surrounding north coast areas dominated by the Chimú reveals some surprises regarding state development in the Andean area. Clearly, irrigation agriculture provided the subsistence base that allowed a certain level of political development by the Chimú. It is *not* the case, however, that the maximum extent of land reclamation for agriculture coincided with the maximum extent of state development and Chimú polity expansion. During the time between ca. A.D. 1050 and the flood of A.D. 1300–1350, when the Chimú invested so much labor in canal and field-system construction, their political control extended over relatively few valleys. Subsequently, as a result of a distinct strategy that focused on more effective control and use of human labor and craft production, the Chimú emerged as an empire spanning 1,300 km of coastal Peru and rivaling the Incas.

Detecting El Niño Evidence in the Archaeological Record: A Cautionary Note

It is clear that evidence of past El Niño events can be detected in the archaeological record of the desert coast of Peru (Moseley 1992:215, 254; T. Pozorski 1987:113; Shimada 1982:180). The stronger the El Niño event, the more likely it is to have a direct impact on archaeological remains. Such impacts can be detected as washed-out areas or distinct laminar deposits in irrigation features, as shown in this paper, or in association with architectural features (Uceda and Canziani 1993).

Detecting individual El Niño events at single archaeological sites is one thing; however, connecting those events with apparently similar-looking events at other sites and areas, either within the same valley or in other valleys, is a much more difficult task. The ability to interconnect El Niño events over increasingly large areas along the coast of Peru would be a powerful chronological tool that could provide dating precision unmatched by any other dating means available in Peru. Furthermore, the impact of strong El Niño events could also provide potential explanations for cultural changes in the archaeological past (von Hagen and Morris 1998:22).

There are two main problems with El Niño correlation in the archaeological record. The first problem is chronology. Precise dating is essential for correlating El Niño events, whether one is connecting areas or sites within a valley or across many valleys. In the present discussion, it is postulated that a major El Niño hit the Moche Valley irrigation system around A.D. 1300–1350, resulting in major repercussions on Chimú political strategy. However, some authors have dated this flood two centuries earlier, to A.D. 1100 (Moseley 1992:254; Nials et al. 1979). Furthermore, this Moche Valley flood has been correlated with an A.D. 1100 flood that occurred in the Lambayeque region (Moseley 1992:252–254; Richardson 1994: 143). We believe that the stratigraphic evidence correlating the flood with the construction sequence of Chan Chan supports an A.D. 1300–1350 date for the Moche Valley El Niño and that it represents an event distinct from the Lambayeque A.D. 1100 El Niño. It is apparent, however, that there is substantial disagreement on this correlation.

This single example points out the chronological problem with El Niño correlation. Here are two El Niño events, separated in time by two centuries, that are nevertheless the source of chronological controversy. The problem can only get more complicated as one deals with El Niño events more closely spaced or more distant in time. Given that major El Niño events affect much of the north and central Peruvian coast at least two or more times per century, and given the relative grossness of dating methods currently available, archaeologists will be hard-pressed to distinguish and date El Niños that occur within 50 years of one another, let alone within 15 years, as is the case with the recent 1983 and 1998 floods.

A second, potentially even more difficult problem is the spatial correlation of strong El Niño events. We were able to correlate the impact of a strong El Niño event over a fairly large area of land by carefully studying stratigraphic relationships of linear features (canals, walls, roads) that intersect in certain places. Most archaeological contexts are not characterized by such linear features, instead involving sites or features that are separated spatially by many kilometers. In some instances, a fairly strong case can be made for correlating a single El Niño between two sites. For example, in the Casma Valley, a major El Niño hit the site of Cerro Sechín around 1200 B.C. Here, a reconstructed floor built on top of a filled-in corridor behind the main mound trapped a pool of water that softened the clay floor, which was then trod upon by several individuals (Fuchs 1997:150–152). Some 5 km away, at the site of Pampa de las Llamas-Moxeke, what were likely the same El Niño waters fell, damaging portions of friezes on the main mound (Huaca A) as well as wetting the floor of an adjacent enclosure upon which several individuals trod, similar to the Cerro Sechín case (Fig. 13).

The Casma Valley case just described is en-

Figure 13. Human footprints on the floor of an enclosure adjacent to Huaca A at the Initial Period site of Pampa de las Llamas-Moxeke in the Casma Valley. The enclosure floor was wetted heavily by an El Niño event dated to about 1200 B.C.

tirely plausible, given the available stratigraphic and radiocarbon evidence, but is by no means conclusively proven. It is often assumed that major El Niño events will bring rains that will more or less uniformly blanket the entire area adjacent to the ocean zone that is penetrated by the Ecuadorian Countercurrent. Observations of rainfall patterns of the 1983 and the 1998 El Niños indicate otherwise. Along the north and north-central coast, some valleys were hit harder than others. Most rainfall came down well inland from the coastline, between elevations of 1000 and 1500 m. Geologically, riverbeds were quite changed as river channels were deepened, substantially widened, and scoured of vegetation. This was quite evident during the 1998 event for every valley between Chicama and Huarmey.

Archaeological sites and modern settlements, however, were more variably affected. In the Casma Valley, the Late Intermediate Period adobe mound site of Sechín Bajo was completely washed away by the swollen Sechín River. One kilometer away, the Initial Period site of Sechín Alto, situated a few hundred meters south of the Sechín River, was only minimally affected by rainfall that resulted in a few thin patches of silt that settled from small puddles of water. In the modern town of Casma, there were episodes of rainfall during March 1998. During one particularly heavy downpour that lasted some two hours, the south part of town was drenched by several centimeters of rain, whereas the north part of town, 0.5 km away, received less than 1 cm of rain. This uneven distribution of rainfall during El Niño events should not be surprising to anyone who has experienced rainfall, and there is no reason to assume that El Niño rainfall patterns should be any different.

The main point of this discussion is to highlight the difficulties of El Niño correlation. There are problems associated with both the temporal and spatial correlations of El Niño events documented from different areas of coastal Peru. El Niño events that leave abundant evidence in several places can potentially reveal important chronological and cultural information, yet careful study is needed to make precise correlations. A more difficult task is the correlation of El Niños that leave behind only widely scattered pieces of evidence. What appears to be a major El Niño event in one valley may leave only minimal or no evidence in another valley or even in another part of the same valley. The absence of evidence of an El Niño event at a particular site does not mean that such an event did not happen. All this means is that the particular El Niño event did not happen to affect the one site in question. What remains a challenge to both archaeologists and geomorphologists alike is the documentation and correlation of El Niño events and their physical and cultural effects. This can only be done through a long series of careful, detailed studies that will need to be carried out over the next few decades.

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Literature Cited

Burger, R. 1992. Chavin and the Origins of Andean Civilization. Thames and Hudson, London.

Day, K. 1980. Las ciudadelas de Chanchán, pp. 155–158. *In* R. Ravines, ed., Chanchán: Metrópoli Chimú. Instituto de Estudios Peruanos, Lima, Peru.

———. 1982. Ciudadelas: Their form and function, pp. 55–66. *In* M. Moseley and K. Day, eds., Chan Chan: Andean Desert City. University of New Mexico Press, Albuquerque.

Donnan, C. 1978. Moche Art of Peru. Museum of Cultural History, University of California, Los Angeles.

———. 1990. An assessment of the validity of the Naymlap Dynasty, pp. 243–274. *In* M. E. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Farrington, I. 1974. Irrigation and settlement pattern: Preliminary research results from the north coast of Peru. *In* T. E. Downing and M. Gibson, eds., Irrigation's Impact on Society. Anthropological Papers of the University of Arizona, **25:** 83–94.

———. 1980. The archaeology of irrigation canals, with special reference to Peru. World Archaeology, **11:** 287–305.

Farrington, I., and C. C. Park. 1978. Hydraulic engineering and irrigation agriculture in the Moche Valley, Peru: A.D. 1250–1532. Journal of Archaeological Science, **5:** 255–268.

Fuchs, P. 1997. Nuevos datos arqueométricos para la historia de ocupación de Cerro Sechín—Período Lítico al Formativo, pp. 145–161. *In* E. Bonnier and H. Bischof, eds., Archaeológica Peruana, vol. 2. Sociedad Arqueológica Peruano-Alemana and Reiss-Museum Mannheim, Heidelberg.

Keatinge, R. 1974. Chimú rural administrative centers in the Moche Valley, Peru. World Archaeology, **6:** 66–82.

———. 1980. Centros administrativos rurales, pp. 283–298. *In* R. Ravines, ed., Chanchán: Metrópoli Chimú. Instituto de Estudios Peruanos, Lima, Peru.

Keatinge, R., and K. Day. 1973. Socio-economic organization of the Moche Valley, Peru, during the Chimú occupation of Chan Chan. Journal of Anthropological Research, **29:** 275–295.

———. 1974. Chan Chan: A study of precolumbian urbanism and the management of land and water resources in Peru. Archaeology, **27:** 228–235.

Klymyshyn, U. 1982. Elite compounds in Chan Chan, pp. 119–143. *In* M. Moseley and K. Day, eds., Chan Chan: Andean Desert City. University of New Mexico Press, Albuquerque.

———. 1987. The development of Chimú administration in Chan Chan, pp. 97–110. *In* J. Haas, S. Pozorski, and T. Pozorski, eds., The Origins and Development of the Andean State. Cambridge University Press, Cambridge, U.K.

Kolota, A. 1982. Chronology and settlement growth at Chan Chan, pp. 67–85. *In* M. Moseley and K. Day, eds., Chan Chan: Andean Desert City. University of New Mexico Press, Albuquerque.

———. 1990. The urban concept of Chan Chan, pp. 107–144. *In* M. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Kosok, P. 1965. Life, Land and Water in Ancient Peru. Long Island University Press, New York.

Kus, J. 1972. Selected Aspects of Irrigated Agriculture in the Chimú Heartland, Peru. Ph.D. diss., Department of Geography, University of California, Los Angeles.

———. 1984. The Chicama-Moche Canal: Failure or success? An alternative explanation for an incomplete canal. American Antiquity, **49:** 408–415.

Mackey, C. 1987. Chimú administration in the provinces, pp. 121–129. *In* J. Haas, S. Pozorski, and T.

Pozorski, eds., The Origins and Development of the Andean State. Cambridge University Press, Cambridge, U.K.

Mackey, C., and A. M. Ulana Klymyshyn. 1990. The Southern frontier of the Chimú Empire, pp. 195–226. *In* M. E. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Morris, C., and A. von Hagen. 1993. The Inka Empire and its Andean Origins. American Museum of Natural History and Abbeville Press, Inc., New York.

Moseley, M. 1992. The Incas and Their Ancestors. Thames and Hudson, London.

Nials, F., E. Deeds, M. Moseley, S. Pozorski, T. Pozorski, and R. Feldman. 1979. El Niño: The catastrophic flooding of coastal Peru. Field Museum of Natural History Bulletin, **50**(7): 4–14; **50**(8): 4–10.

Ortloff, C. 1981. La ingeniería hidráulica Chimú, pp. 91–134. *In* H. Lechtman and A. Soldi, eds., La tecnología en el mundo Andino. Universidad Nacional Autónoma de Mexico, Mexico City.

———. 1988. Canal builders of ancient Peru. Scientific American, **256**(12): 67–74.

———. 1993. Chimú hydraulics technology and statecraft on the north coast of Peru, AD 1000–1470. *In* V. Scarborough and B. Isaac, eds., Research in Economic Anthropology, Supplement, **7:** 327–367.

———. 1995. Surveying and hydraulic engineering of the pre-Columbian Chimú state: AD 900–1450. Cambridge Archaeological Journal, **5**(1): 55–74.

Ortloff, C., R. Feldman, and M. Moseley. 1985. Hydraulic engineering and historical aspects of the pre-Columbian intravalley canal systems of the Moche Valley. Journal of Field Archaeology, **12:** 77–98.

Ortloff, C., M. Moseley, and R. Feldman. 1982. Hydraulic engineering aspects of the Chimú Chicama–Moche Intervalley Canal. American Antiquity, **47:** 572–595.

Patterson, T. 1985. The Huaca La Florida, Rimac Valley, Peru, pp. 59–69. *In* C. B. Donnan, ed., Early Ceremonial Architecture in the Andes. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Pozorski, S. 1987. Theocracy vs. militarism: The significance of the Casma Valley in understanding early state formation, pp. 15–30. *In* J. Haas, S. Pozorski, and T. Pozorski, eds., The Origins and Development of the Andean State. Cambridge University Press, Cambridge, U.K.

Pozorski, S., and T. Pozorski. 1979. An early subsistence exchange system in the Moche Valley, Peru. Journal of Field Archaeology, **6:** 413–432.

———. 1987. Early Settlement and Subsistence in the Casma Valley, Peru. University of Iowa Press, Iowa City.

Pozorski, T. 1982. Early social stratification and subsistence systems: The Caballo Muerto complex, pp. 225–253. *In* M. E. Moseley and K. C. Day, eds., Chan Chan: Andean Desert City. University of New Mexico Press, Albuquerque.

———. 1987. Changing priorities within the Chimú state: The role of irrigation agriculture, pp. 111–120. *In* J. Haas, S. Pozorski, and T. Pozorski, eds., The Origins and Development of the Andean State. Cambridge University Press, Cambridge, U.K.

Pozorski, T., and S. Pozorski. 1982. Reassessing the Chicama-Moche Intervalley Canal: Comments on 11Hydraulic engineering aspects of the Chicama-Moche Intervalley Canal." American Antiquity, **47:** 851–868.

———. 1990. Huaynuná, a Late Cotton Preceramic site on the north coast of Peru. Journal of Field Archaeology, **17:** 17–26.

Richardson, J. 1994. People of the Andes. *In* J. Sabloff, ed., Exploring the Ancient World. St. Remy Press, Montreal, and Smithsonian Institution, Washington, D.C.

Richardson, J., M. McConnoughy, A. Heaps de Peña, and E. Decima Zamecnik. 1990. The northern frontier of the kingdom of Chimor: The Piura, Chira, and Tumbez Valleys, pp. 419–445. *In* M. E. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Rowe, J. 1948. The kingdom of Chimor. Acta Americana, **6:** 26–59.

Shimada, I. 1982. Horizontal archipelago and coast-highland interaction in north Peru: Archaeological models, pp. 137–210. *In* L. Millones and H. Tomoeda, eds., El hombre y su ambiente en los Andes Centrales. Senri Ethnological Studies 10. National Museum of Ethnology, Osaka.

———. 1990. Cultural continuities and discontinuities on the northern north coast of Peru, Middle-Late Horizons, pp. 297–392. *In* M. E. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Stuiver, M., and B. Becker. 1993. High-precision decadal calibration of the radiocarbon time scale, A.D. 1950–6000 B.C. Radiocarbon, **35**(1): 35–65.

Topic, J., and M. Moseley. 1983. Chan Chan: A case study of urban change in Peru. Ñawpa Pacha, **21:** 153–182.

Topic, T. L. 1990. Territorial expansion and the kingdom of Chimor, pp. 177–194. *In* M. E. Moseley and A. Cordy-Collins, eds., The Northern Dynasties: Kingship and Statecraft in Chimor. Dumbarton Oaks Research Library and Collection, Washington, D.C.

Uceda, S., and J. Canziani. 1993. Evidencias de grandes precipitaciones en diversas etapas constructivas de la huaca de la luna, costa norte del Peru. Bulletin de L'Institut Français d'Études Andines, **22**(1): 313–343.

von Hagen, A., and C. Morris. 1998. The Cities of the Ancient Andes. Thames and Hudson, London.

6

El Niño, Early Peruvian Civilization, and Human Agency: Some Thoughts from the Lurin Valley

Richard L. Burger

The role of El Niño in the rise and fall of early Andean civilizations has attracted increasing attention over the past two decades as more has become known about the role of climate change in human history. It is no coincidence that this greater sensitivity to climate change in the archaeological past has emerged as we have become increasingly anxious about global warming and the way it could affect our future. As science has focused more intently on global climatic change, new methods and theories have been developed that allow us to reconstruct past climates and to appreciate the degree of variability that has existed in the Holocene climate, of which the El Niño phenomenon is but one small piece.

The past two decades also saw two major El Niño events. As a consequence, many archaeologists working in Peru have experienced, either firsthand or through media coverage, the devastation that a major El Niño event can produce. By contrast, in 1980, only the most senior archaeologists had personally experienced a major Niño event, and most academics had to rely on accounts of the 1925 El Niño to imagine what its effects were like. Thus, historical happenstance has placed scholars in a situation where there are now both personal experience and the academic predisposition to take El Niño seriously in the archaeological modeling of civilizational trajectories in the distant past. Such was not always the case. In the late 1960s, for example, both Edward Lanning (1967) and Luis Lumbreras (1969) found it possible to write syntheses of Andean prehistory with barely a reference to the El Niño phenomenon, and the immediately previous generation of scholars, such as Bushnell (1957) and Bennett and Bird (1960), ignored El Niño entirely. Such an approach has now been largely supplanted, as evidenced by the work of Michael E. Moseley (1992) and James Richardson III (1994), in which El Niño figures prominently as a possible contributing factor to the emergence, expansion, reorganization, and demise of multiple Peruvian cultures, including those of Chavín, Moche, and Chimu.

Recent archaeological literature on the possible effect of El Niño on Andean prehistory has usually focused on the role of El Niño in the evolution of Andean civilization. A classic example was a 1981 article by David Wilson, in which he posited the El Niño phenomenon as a limiting factor in the development of an early maritime civilization in the Central Andes because of the unpredictable but radical reduction in maritime carrying capacity along the coast during major El Niño events. In a more recent 1999 synthesis, Wilson (1999:352–356) updated his earlier argument and suggested that the stresses caused by El Niño could help explain how a primarily maritime-oriented people might accept agriculture as an alternative strategy, thus creating the conditions for the emergence of complex society. In the models proposed by Wilson and others, El Niño is seen as shaping a long-term evolutionary trajectory as cultures become adapted to their environmental conditions; the role of human actors and their strategies is seen as secondary to larger evolutionary processes. Not surprisingly, such models have been criticized as treating humans as fundamentally passive and as constructing social change merely as a process of reacting to natural phenomena, such as natural disasters or long-term changes in climate. Although such models have merit, it also is important to consider whether the peoples of pre-Hispanic Peru anticipated the dangers posed by El Niño events and whether they were able to develop strategies to mitigate them. In adopting this second approach, we recognize that human agency played an important role in determining cultural stability and change in the past, just as it does in the present.

In the modern world, major disasters are most successfully dealt with at the level of the nation-state or international community. For example, 90% of the $14 billion in aid to the victims of the 1994 California earthquake came from the federal government of the United States rather than from local or state sources, and in Honduras, virtually all aid to alleviate the devastation wreaked by Hurricane Mitch has come from governmental and charitable sources outside of Central America (Davis 1998). But what disaster strategies were employed prior to the emergence of such overarching social and political structures?

Possible Pre-Hispanic Responses to El Niño Events in the Central Andes

In the absence of state-based systems, one way of dealing with recurring environmental disruptions such as El Niño is for families or small social units to develop links with distant communities that are less likely to be affected by the environmental perturbation. In the case of the northern and central coast of Peru, for example, longstanding links with adjacent highland communities would have facilitated a prehistoric alternative to current disaster relief, perhaps under the rubric of fictive kinship obligations or gift exchange. At the 1982 conference on Early Monumental Architecture at Dumbarton Oaks, I suggested that in combination with the dietary needs of highlanders (e.g., for iodine and salt), the danger presented by El Niño events would have favored the establishment of ties between highland and coastal groups that could be mobilized in times of disaster. Llama caravans could have brought highland agricultural produce down to communities where an El Niño had devastated both the year's crops and maritime productivity (Burger 1985:276).

A modern version of such a strategy was mentioned in Robert Murphy's description of the 1925 El Niño, in which food shortages on the central coast were solved by "mutton on the hoof" driven down from the high grasslands (*puna*) and by pack trains of llamas, horses, and burros from the highland valleys carrying potatoes and other foodstuffs (Murphy 1926:46). The continued viability of agricultural systems in the northern highlands during the last two major Niño events supports the plausibility of this idea.

Moreover, recent research by Ruth Shady (1997) at Caral in the Supe Valley and by Shelia and Thomas Pozorski (1992) at Huaynuná and Pampa de las Llamas in Casma has reinforced our appreciation of the Late Preceramic and Initial Period links between the highland societies involved in the Kotosh Religious Tradition and their contemporaries in centers on the coast. Unfortunately, the hypothesis of highland economic assistance to coastal settlement during El Niño events has yet to be tested on a microlevel by studying examples of a Late Preceramic or Initial Period center that coped with an El Niño event. It would be fascinating to know if the survival strategy of such a site was characterized by refuse that included a sharp increase in the amounts of highland meat and agricultural produce to compensate for the disruption of marine and lower-valley agricultural resources.

In Andean archaeology, one of the rare instances of a local-level analysis of a prehistoric community struggling to deal with an El Niño event is the study of two Chimu settlements in the Casma Valley by Jerry Moore (1991). Moore not only used archaeology to document the occurrence of a fourteenth century A.D. El Niño event, he also explored some of the cultural responses to it. He concluded that immediately following a powerful El Niño, the Chimu state established a complex of ridged fields in order to reclaim waterlogged soils, and an adjacent community to house agricultural workers. This subsistence system was apparently maintained for no more than a few years, while the normal farming system was restored, after which time the site was abandoned. According to Moore, by shifting to the cultivation of fields that were not irrigated, along with exploiting El Niño-resistant species of shellfish, it was possible to support the continued occupation of the Casma Valley and its administrative center at Manchan despite the devastation wreaked by a major El Niño event. This case is particularly interesting because it illustrates how one pre-Hispanic group consciously combined two of many possible strategies in order to cope with the conditions created by El Niño. In this case, the rains from El Niño may have created the opportunity for successful dry-farming in this section of the normally arid coast.

Given recent history, it should not be news to anyone that El Niños produce occasional opportunities as well as serious problems. One has only to recall the scandal that occurred during the 1982–1983 El Niño, when several high-ranking military men were accused of using army cargo planes to fly cattle down from Panama to graze on the vast pasturelands that had appeared in Peru's Sechura Desert. The appearance of more robust *lomas* vegetation, the migration of new kinds of fish, the short-term availability of new land for rainfall farming, and the sprouting of new pastures may be only small consolation when weighed against the enormous losses occasioned by an El Niño event, but such factors may have been crucial for crafting locally based survival strategies in pre-Hispanic times. Additional studies along the lines of the Casma research should yield greater insight into the significance of these alternatives. It should be noted that the strategy posited by Moore for Casma involved the intervention of state institutions, which were absent in much earlier prehistoric times.

Pre-Hispanic Human Agency, El Niño, and the Manchay Culture

Thus far I have explored some of the possible short-term responses to the effects of El Niño events in the pre-Hispanic Central Andes. However, as geographer Kenneth Hewitt has observed, "Most natural disasters are characteristic rather than accidental features of the places and societies where they occur" (Davis 1998: 52). In the longer-term perspective, humans can be considered agents that, with the accumulated knowledge of their landscape, either learn to anticipate potential disasters and avoid them or choose to ignore the dangers and place themselves in harm's way. Mike Davis's book, *The Ecology of Fear* (1998), provides an excellent illustration of this perspective. He shows how flawed human decisions acted to turn tectonic and climatic forces into major dangers in the course of human settlement in southern California.

Following in this line of thought, I want to consider here whether the coastal societies of Peru during the second millennium B.C. (known as the Initial Period) perceived the possible threat posed by the El Niño phenomenon, and if they did, what actions they may have taken to protect themselves. In the Central Andes, this period of time is of particular interest to those interested in the relationship between El Niño and the appearance of complex societies because it was the time of the emergence of the region's earliest civilizations. Among the accomplishments of the coastal cultures of the Initial Period were the creation of abundant monumental architecture, the production of sophisticated public art, breakthroughs in metallurgical techniques, and the building of extensive irrigation systems. This Initial Period culture, characterized by massive civic-ceremonial centers with a U-shaped layout, extended along the central coast from Chancay Valley on the north to Lurin Valley on the south. Investigations of these U-shaped centers of Manchay culture by myself and Lucy Salazar (Burger 1992:60–75; cf. Silva and García 1997) have focused on the southernmost of these valleys, which is located immediately south of contemporary Lima, and the following commentary is based on our ongoing research.

During the second millennium B.C., the population in the lower Lurin Valley gradually increased, as reflected in the founding of civic-ceremonial centers that served as the focus of small-scale social units. Only one such center is known to have existed in 1800 B.C., but by 1000 B.C., at least six such centers appear to have been functioning in the lower valley, and several more in the middle valley (Fig. 1). These centers appear to have been autonomous and were not organized by an overarching state apparatus; the latter appeared only much later in the prehistory of the central coast. The pop-

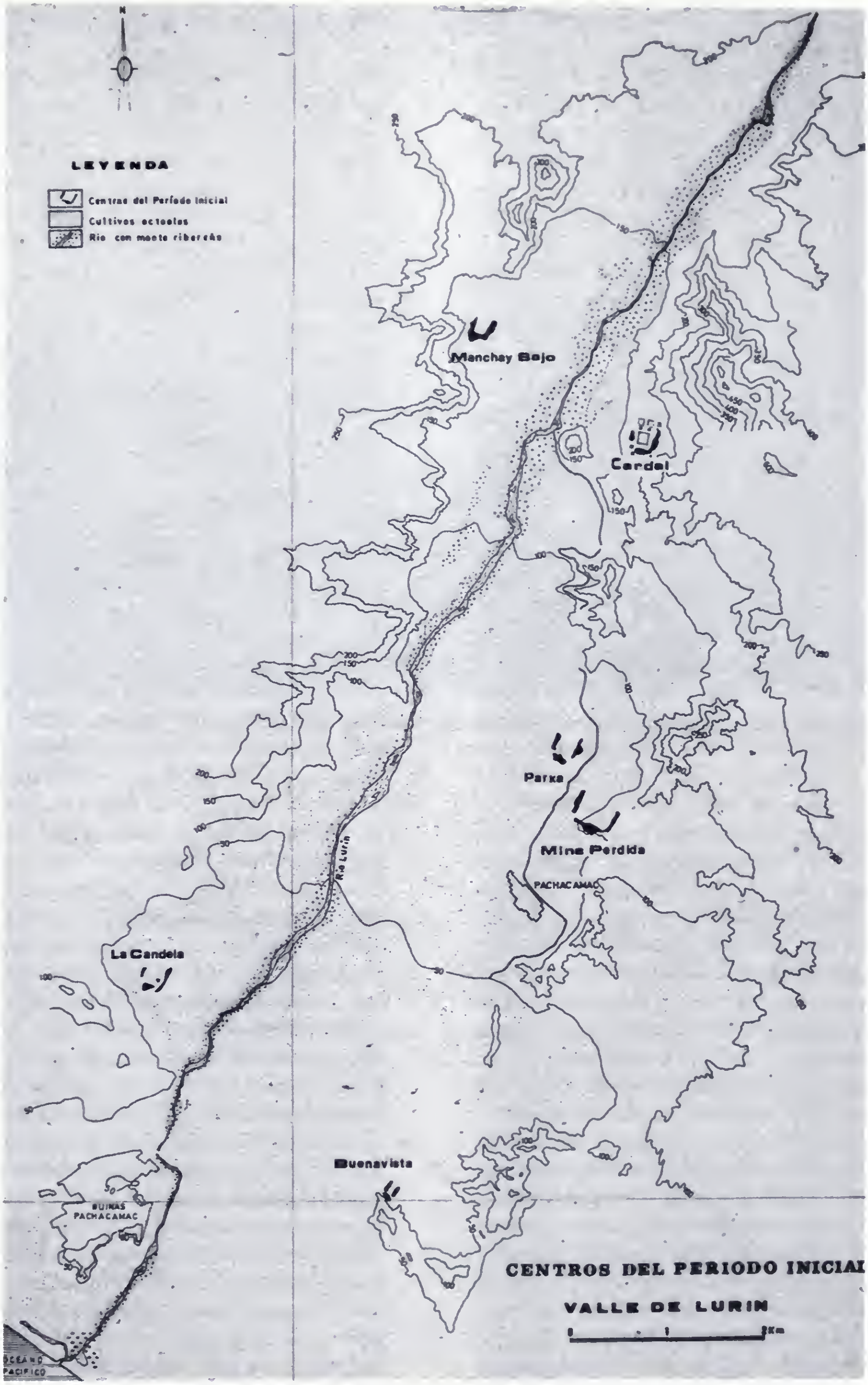

Figure 1. The location of Initial Period U-shaped pyramid complexes in the lower Lurin Valley, Peru. (Map drawn by Bernadino Ojeda.)

ulation supporting these centers survived on a mixed subsistence system based on irrigation farming of crops such as squash, peanuts, beans, red pepper, guava, pacae, and lucuma, as well as yet unidentified tubers (sweet potato?), manioc, and a small amount of maize. These domesticated crops were supplemented by the collection of wild plants, the acquisition of fish and mollusks from the Pacific shore, and the hunting of deer, camelids, vizcachas, and birds from nearby *lomas* and riverine environments (Benfer and Meadors 2002; Burger and Salazar-Burger 1991; Umlauf 2002).

The largest of the valley's centers, Mina Perdida, was occupied for about a thousand years (calibrated C14 years) without evidence of hiatus or abandonment (Burger and Salazar-Burger 1998, 2002). If one accepts the proposition that the pattern of El Niño events was established by 5,800 years ago (Rollins et al. 1986), the Manchay culture in Lurin presents an example of cultural continuity and resilience for at least ten centuries in the face of the major El Niño events that must have occurred during this time. Even if one accepts that El Niño had a longer recurrence interval until 3200–2800 cal B.P. (Sandweiss et al. 2001), the centers of the Manchay culture would still have experienced numerous major El Niño events, a fact confirmed by the research I shall describe below.

Considering the dangers posed by El Niño events, the choice of location for Lurin's U-shaped centers was not auspicious; in fact, to use Mike Davis's phrase, it could be said that the groups living in the lower Lurin Valley chose to place their centers in harm's way. The public complexes were generally built at the mouth of deeply cut ravines (*quebradas*). These *quebradas* were normally bone dry, but they sometimes carry water during El Niños. Such locations may have been chosen because they provided expanses of relatively level land adjacent to the valuable irrigated bottomlands of the valley. Moreover, the nearby rocky ravines and barren valley sides offered ample building materials, including stone blocks and lenses of clay suitable for mortar and adobes. Unfortunately for the inhabitants of these centers, the loose rock, rubble, and earth in these *quebradas,* which make such good building materials under normal circumstances, are incorporated into landslides and debris flows when heavy rainfalls occur in the lower Lurin Valley during major El Niño events.

Manchay Bajo and Its Monumental Wall

Judging from the results of fieldwork in 1998 and 1999 by the Yale University Lurin Valley Archaeological Project at Manchay Bajo, the Initial Period occupants of Lurin not only were aware of the danger posed by an El Niño event, they consciously worked to protect themselves against potential disasters. Manchay Bajo (PV48–147) is located in the lower valley, 12 km inland from the Pacific, at 140 m above sea level (masl). In contrast to the U-shaped complexes of Mina Perdida and Cardal, Manchay Bajo is on the northern bank of the Lurin River, only 800 m from the current course of the river.

Manchay Bajo is, in most respects, a typical U-shaped complex. The archaeological complex is dominated by a terraced, flat-topped central pyramid (Fig. 2), and the site is oriented to the northeast. The pyramid, found at the apex of the U, measures 100 × 75 m at its base and rises 13 m above the current level of the valley floor. Two elongated lateral mounds, one of which is attached to the main pyramid, flank a central plaza that is 3 hectares in area (Fig. 3). Although lower than the main mound, the lateral mounds are of considerable size, with heights of 11 m and 8 m, respectively. The area of the site, roughly 20 hectares, and the scale of the monumental architecture are slightly larger than at Cardal, which is located 1.7 km away on the other side of the river. The excavations at Manchay Bajo revealed a long history of construction at the center that included a minimum of nine superimposed central stairways, three superimposed atria, each with multiple renovations, and at least nine major building episodes. Thus, the large public constructions seen today were the result of repeated constructions that spanned at least six centuries.

Most of the ceramics associated with the monumental constructions date to the late Initial Period (approximately 1200–800 cal. B.C.). This is consistent with an AMS measurement of 3010 ± 60 (AA 3442), which, when calibrated, has a 2σ range of 1404–1052 B.C.; the specimen tested comes from a fiber bag (*shicra*) used to hold stone in the fill covering the site's middle atrium. Since this measurement dates the closing of this structure, and since an even older atrium exists below this one, Manchay Bajo must have been founded significantly before this time. Although most of the construction episodes at Manchay Bajo date to the late Initial

Figure 2. Central mound at Manchay Bajo, Lurin Valley, during the 1998 excavations on the summit terraces. Modern agricultural constructions visible on the lower left are encroaching on the archaeological site. (Photograph by Richard L. Burger.)

Period, the uppermost levels yielded a distinctive ceramic assemblage that dates to the Early Horizon; no hiatus is indicated (Fig. 4). The preliminary stylistic interpretation of the pottery is consistent with two AMS C14 measurements of 2560 ± 50 B.P. (Beta-122683) and 2600 ± 50 (AA 34441) from the final period of construction which, when calibrated, produced a 2σ range between 815–525 B.C. and 894–539 B.C., respectively. Thus, the available evidence indicates that whereas Manchay Bajo was contemporary with Cardal and Mina Perdida during the final centuries of the Initial Period, it continued to function as a civic-ceremonial center for a century or more after the others were abandoned (Fig. 5). Manchay Bajo is situated at the mouth of two *quebradas* that were incised into the Andean spur separating Lurin from the Rimac drainage (Fig. 6). The larger of these, known today as the Quebrada Manchay, is a dry tributary valley located to the north of Manchay Bajo. It is separated from the valley through which the Lurin River flows by a massive rocky spur (246 masl). The smaller of the two *quebradas* is located to the northwest of the site and is unnamed; it extends only for about a kilometer. The Quebrada Manchay was used as a natural corridor between the Lurin and Rimac in prehistoric times, and this route continues to be used today despite the poor state of the unpaved road. Given the nature of the topography and Manchay Bajo's location, a major El Niño could have triggered landslides through the large Quebrada Manchay, which would have buried the site's central plaza in stone rubble. A debris flow from the shorter, unnamed lateral *quebrada* would have had a strong effect on the western lateral platform of Manchay Bajo. Undeterred debris flows from either or both *quebradas* would have had the greatest impact on the residential zone covering the flatland to the north and northwest of the public architecture.

The potential danger posed for prehistoric occupations and public spaces by landslides and debris flows from the small lateral *quebrada* was highlighted by the excavations at the site of Pampa Chica by archaeologists from the

Figure 3. Topographic map of the Manchay Bajo complex indicating the location of excavation units and the monumental wall extending along the western and northern extremes of the site. (Map drawn by Bernadino Ojeda.)

Pontificia Universidad Católica (PUC), Lima, under the direction of Jalh Dulanto as part of the Proyecto Arqueológico Tablada de Lurin, directed by Krzysztof Makowski. Pampa Chica, a small site located up the smaller of the two *quebradas* at 180 masl, had been covered by landslides. Occupied between the Early Horizon and the Middle Horizon, investigations at

Figure 4. Incised fragment of a polished blackware vessel depicting a frontal face with two large fangs. This sherd from Manchay Bajo illustrates the pottery associated with the final phase of construction at the U-shaped pyramid complex. (Photograph by Richard L. Burger.)

the site found evidence of repeated debris flows in prehistoric times (Dulanto et al. 2002).

In addition to the danger posed to Manchay Bajo by flash floods and debris flows coming out of the Quebrada Manchay and the smaller lateral *quebrada,* a threat also was posed by a 138-m-high rocky outcrop (278 masl) immediately to the west of the main mound (Fig. 7). It is covered with large stone boulders and loose stone rubble, and this unconsolidated material would have become unstable during an El Niño event or an earthquake.

Prior to 1998, no topographic map of the entire archaeological site of Manchay Bajo existed. However, Harry Scheele (1970:179–190) had carried out test excavations at the site in 1966 and produced a sketch map of the central portion of the site. In subsequent years, many visitors, including Alberto Bueno Mendoza, members of the PUC Pampa Chicha team, and me, have examined Mancho Bajo and been intrigued by a large wall that rings its western and northern perimeter. Our investigations included a detailed mapping of the entire site, and it was determined that the massive wall begins at a rocky outcrop near the southwest corner of the northwest lateral platform and runs in a northerly direction for some 460 m. The wall then turns eastward and runs for another 240 m (see Fig. 3). Unfortunately, its final section was destroyed by the construction of a modern road, but it appears that the eastern end terminated 45 m away, at the large rocky outcrop that defines the eastern edge of the Quebrada Man-

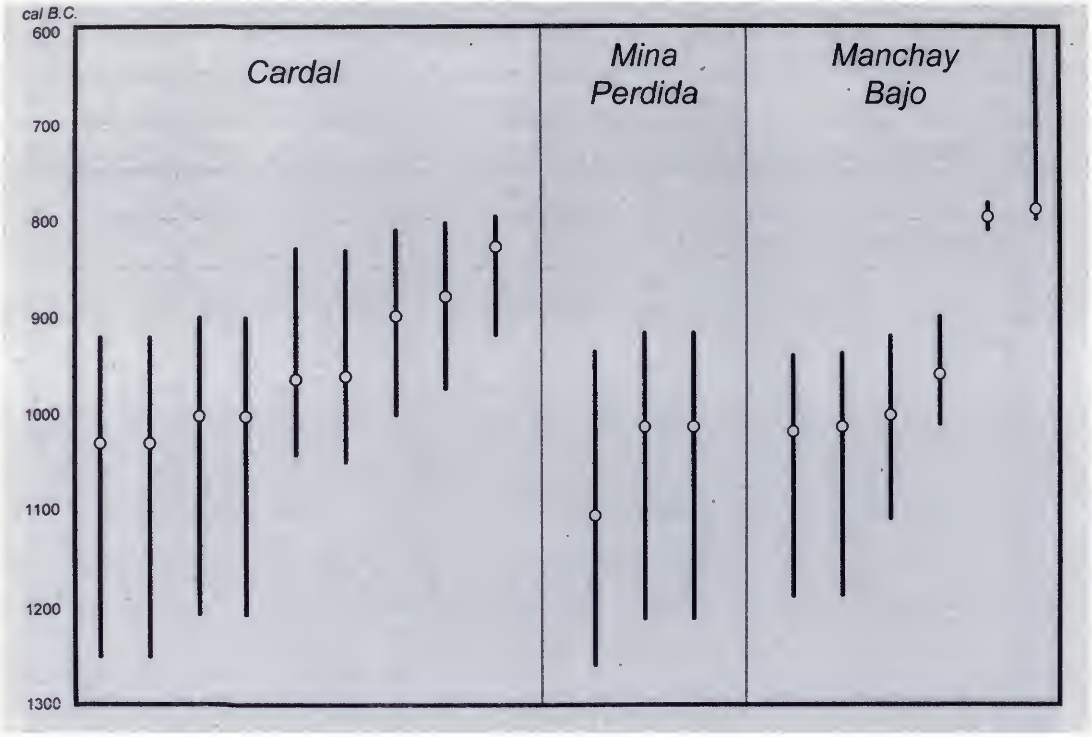

Figure 5. Radiocarbon measurements from the three U-shaped complexes excavated in the Lurin Valley demonstrate both the general contemporaneity of the centers and the continued occupation of Manchay Bajo after the abandonment of the other two sites. (Chart by George Lau.)

chay. Both of the two extremes of the monumental wall appear to have been engaged with natural topographic features anchoring this remarkable cultural feature to the landscape. The total length of the original wall is estimated at 745 m.

During the mapping and surface survey in 1998, masonry retaining walls could be seen at various points along both the north-south and east-west segments of the perimetric wall. In those sections where it has been exposed, the original wall can be seen to be double-faced, with a core of unconsolidated stone, gravel, and earth. In both segments there is evidence of at least one and in some cases two renovations of the wall; this was done by adding new walls separated from the previous walls by a layer of fill. These additions would have widened the wall substantially while reducing strain on the walls incorporated into the core. This same pattern of growth was determined for the terrace walls on the central pyramid of the Manchay Bajo complex. Like the Manchay Bajo's platform constructions, construction of the original monumental wall and its subsequent renovation were carried out with medium-sized blocks of roughly dressed stone from the nearby slopes (Fig. 8). Clay mortar was used at the junctures, but during the surface reconnaissance, no surviving evidence of surface plastering was encountered. The width and height of the wall varied, and in many places its limits are completely hidden under collapsed or accumulated material. Nevertheless, the topographic map suggested that the north-south segment had an average width of about 12.5 m and an average height of at least 5 m, and portions of the east-west segment were still more massive. Surface ceramics were encountered at various points on the summit of the wall; they were particularly common near its eastern end because of disturbance from the modern construction of a small chapel on top of the wall. Based on vessel forms and decoration, all of the pottery can be dated to the late Initial Period. It included numerous shallow open bowls and neckless ollas. Some of the former had the vessel interior decorated with broad incisions. The surface ceram-

Figure 6. Aerial photograph of Manchay Complex taken in 1945 displaying the relation of the pyramid complex to the two ravines or *quebradas* (on the viewer's left and upper left) and the Lurin River (on the viewer's right). The monumental wall can be seen anchored to two rocky outcrops to the west and north of the site. (Courtesy of Servicio Aereofotográfico Nacional, Lima.)

ics found on the wall in 1998 were indistinguishable from those found in the excavations of the main mound at Manchay Bajo that same year. No later ceramics were on or near the wall. Based on the masonry style of the surface architecture and the ceramic evidence, a preliminary conclusion was reached that the monumental wall had been constructed during the Initial Period and was roughly contemporary with the adjacent U-shaped public architecture.

Following the mapping and study of the monumental wall just described, we encountered another masonry feature at the foot of the steep rocky outcrop to the west of the main pyramid (Fig. 9). Cut by a modern canal, ancient floors and fills were exposed, and these were reminiscent of features such as circular courts such as those found at Cardal. However, clearing and excavation in this area revealed that the remains actually corresponded to another massive wall running for at least 105 m, with a width of 5 m and a height of 5 m. The stonework and construction were similar to those already described, and there was evidence of two episodes of renovation in which additional walls were added. In the 1998 excavations of a small section of this wall, late Initial Period pottery was recovered from intact floor surfaces along the wall's eastern face. This evidence, combined with the construction style and technique, lends support to the conclusion that this and the other monumental walls at Manchay

Figure 7. Rocky outcrop immediately to the west of the Manchay Banjo complex. Traces of the monumental wall at the foot of the outcrop were visible prior to excavation and can be seen near the stadia rod in this 1998 photograph. (Photograph by Richard L. Burger.)

Figure 8. Excavation in 1999 of the eastern face of the monumental wall at Manchay Bajo. (Photograph by Richard L. Burger.)

Bajo are coeval with the platform complex and were built by the same population. It is hypothesized that this wall was built to protect the area of the central mound from debris slides coming from the steep slopes of the rocky outcrop above it. Thus, the total extent of the monumental perimetric wall at Manchay Bajo must include this feature as well, bringing the total length of the wall constructions to some 850 m. If a rough calculation is made of the volume of earth and stone moved to construct these walls, it produces a figure in excess of 30,000 m^3.

In 1999, during the second field season, archaeological excavations were carried out in a small section of the monumental wall (Sector VIIA, Excavation 3) in order to clarify its date, construction history, and the building techniques utilized. The work in this sector was supervised by Marcelo Saco (PUC), and technical assistance in the interpretation of the stratigraphy was provided by the Polish sedimentologist, Krzyzstof Mastalerz. The excavated units were located along the wall's north-south section, which crosses the mouth of the small lateral *quebrada* to the west of the site. Initially, 7 m of the eastern face of the wall was cleared (see Fig. 8). This revealed that the southern half of this section was well-preserved, while the northern half had collapsed after the site's abandonment. Subsequent excavations in the area focused on the intact portion of the wall; the zone investigated had an area of 49 m^2. This included a 1-m-wide trench perpendicular to the wall face. At the conclusion of this excavation, a 17-m east-west transect of the monumental wall complemented the horizontal exposure of the wall's eastern face (Fig. 10).

Judging from the excavations, the original monumental wall in this area was trapezoidal in cross-section. The hearting of the wall consists of loose soil, gravel, and stones. The wall was built on a sloping surface created by ephemeral sheet flows that predated the occupation of the site. Both faces of the wall consisted of roughly quarried medium-size stones (e.g., 40 × 38 cm) set in mud mortar. Both sides of the wall cant inward for greater stability, and as a result, the upper section of the wall is approximately 2 m in width and nearly 3 m wide at its base. The upper section of the original wall was missing.

Figure 9. The clearing of the masonry visible at the foot of the western rocky outcrop revealed the eastern face of a monumental wall in association with Initial Period ceramics. Loose rock can be seen on the steep slopes above the wall. (Photograph by Richard L. Burger.)

Figure 10. A trench transecting the monumental wall revealed the western face of the original monumental wall and evidence for two subsequent enlargements. The trowel rests upon a caliche-like layer formed as the result of floor deposits pooling up against the western face of the enlarged wall; this layer is absent on the interior or eastern side of the wall. (Photograph by Richard L. Burger.)

It was feasible to reach the wall base on the western face, and it can be demonstrated that the original wall was over 2 m in height.

Later in the history of Manchay Bajo, the wall was widened by stone retaining walls built parallel to the faces of the original wall. Along the eastern face the new retaining wall was terraced. The lower terrace was 1 m in height, and 1.2 m remains of the upper terrace wall. Along the western face, sterile fills of gravel and stone were added, completely burying the original wall. The massive layers piled against the wall's original western face were studied in terms of their sorting and position, to determine whether they were man-made construction fills or the result of slumps or debris flows from the lateral *quebrada.* These layers include loose, fragmented material ranging from angular boulders to muddy, coarse-grained sand. Sedimentologist K. Mastalerz (1999) concluded that they were man-made deposits piled against the western side of the original wall. These fills added at least 1 m in height and 4 m in width to the monumental wall, bringing the total scale of the wall in this section to over 9 m in width and over 3 m in height.

Interestingly, the floor articulating with the western face of the original wall showed evidence of caliche-like cementation due to the precipitation of soluble compounds from groundwater. Mastalerz (1999) believes that such a layer was probably the result of the pooling of water from El Niño rains against the monumental wall. Significantly, this cementation was not encountered along the eastern face of the wall. Little evidence survived of the new western face of the expanded monumental wall due to the narrowness of our trench (1 m); only a limited portion of what remained could be exposed. However, the base of the wall (Muro 6) and its associated floor was identified. Surprisingly, the wall was made of stone-filled *shicra* bags covered with mud mortar. This technique of wall construction was rare at the U-shaped complexes in the Lurin Valley, but it had been identified previously at Mina Perdida (Burger and Salazar-Burger 2002). It was possible to date the fiber used in the *shicra* in order to get an idea of the age of the monumental wall's renovation. The AMS measurement on this sample produced a date of 3020 ± 40 B.P. (calibrated 2σ range of 1389–1129 B.C.). This result confirms the overall contemporaneity of the monumental wall with the U-shaped civic-ceremonial complex and the associated residential constructions at Manchay Bajo. The date suggests that the original monumental wall was built early in the site's history and renovated at least once during the late Initial Period. Judging from the section excavated, that renovation may have involved as much labor as the original construction itself. Finally, it would appear from the caliche layer that a minimum of one major El Niño event occurred after the wall was constructed and while the site was still occupied. It is reasonable to hypothesize that this El Niño event may have stimulated the enlargement of the original wall, since the addition covers the cementation.

There are two other massive layers of gravel and stone that post-date Muro 6. According to Mastalerz, these, like the strata they cover, also are man-made deposits still in their original position. A possible explanation of these strata is that they represent a subsequent second phase of enlargement after the collapse or dismantlement of the *shicra* wall (Muro 6). This enlargement to the west could have involved a retaining wall whose traces have disappeared completely, or, alternatively, as Mastalerz (1999) suggests, the final outer western surface of the monumental wall could have been left as an unfaced embankment. At the end of this hypothetical third construction phase, the monumental wall would have reached 12 m in width and increased in height by at least another 50 cm to 3.5 m. We have no way of directly dating this third episode of wall construction; we suspect that it could date to the final Early Horizon occupation of the public center.

The location of the walls, their massive width, and their substantial height all suggest that they were built as a dam to protect the civic-ceremonial complex from land and rock slides coming off the rocky outcrops and out of the dry *quebradas.* It is significant that walls do not exist to the east or south of the Manchay Bajo complex, where there is no danger of such disasters. Moreover, there is evidence that the walls served their intended purpose with some success. In all four of the transects that we documented in 1998, the surface level outside the wall (i.e., the exterior facing the potential source of debris) was significantly higher than inside the wall (i.e., the interior facing the plaza or platform mounds). It appears that in some areas, 1–2 m of material had accumulated against the wall, presumably from one or more debris flows provoked by El Niños. In one deep cut to the north of the wall made by modern builders, this pattern of debris flow evidently recurred on several occasions both before and after the wall's construction. Judging from our excavations within the wall's perimeter, Manchay Bajo's monumental wall or dam stopped the entry of stone rubble from debris flows, as was intended. In no area inside the wall did we encounter deposits of boulders or large stones carried by landslides or other disasters. The dam also appears to have protected the civic-ceremonial center from floods during the Initial Period and Early Horizon occupation of the site.

Nevertheless, the problem posed by large quantities of flood water blocked by the monumental wall appears to have presented a serious problem. Our investigations revealed that deep layers of water-borne deposits cover most of the site, with the exception of the elevated public architecture. For example, an excavation in the Manchay Bajo's open plaza area (Sector IV, Excavation 1) revealed that the central section of this space featured a low, stone-filled platform at least 1 m in height. This Initial Period construction was buried by over 2 m in flood deposits, which, according to Mastalerz (1999), were the product of six El Niño episodes whose character varied in size and duration. Some layers of sediments were the result of flash floods, while others were produced by powerful floods followed by stagnant water conditions. In one period the rains were sufficient to stimulate in-channel fluvial processes and the resulting deposition of sand and gravel bars at Manchay Bajo. The repeated floods documented by these deposits came primarily from the Quebrada Manchay, and it would appear that the northern section of the dam was breached on numerous occasions during the last 2000 years following the center's abandonment. Considerable numbers of Initial Period artifacts are mixed in with some of these flood deposits, and it is clear that these floods destroyed some of the upper layers of the site's Formative settlement. While there is compelling evidence of destructive floods following Manchay Bajo's abandonment, at the present time there is no evidence that floods disrupted the Initial Period or Early Horizon occupation of the civic-ceremonial center of Manchay Bajo.

Agents and Environment

The evidence summarized here suggests that (1) the people of Manchay Bajo perceived a threat to their center and adjacent agricultural lands from El Niño-related landslides; (2) they were able to generate a solution to the problem using available technology and materials; (3) they were able to mobilize enough labor to complete a dam large enough to protect them from El Niño debris slides; and (4) during some six centuries of occupation, they were able to bring together enough manpower to renovate the dam on at least two occasions by encasing the original wall within new fills and retaining walls. The monumental walls succeeded as bulwarks against the feared landslides, and they are still capable of doing so. These findings highlight the importance of human agency in shaping a culture's destiny; clearly, the actions discussed here were preemptive, anticipating potential threats from unpredictable future El Niño events. The population employed a knowledge of environmental risks to formulate a strategy, and they were able to implement this strategy even though it involved thousands of person-days of labor without immediate short-term benefit.

The case of Manchay Bajo provides a good opportunity to reconsider some of our preconceptions about the ability of different kinds of societies to cope with environmental variability. It has often been assumed that states are uniquely well suited to deal with disasters because of their coercive capacity, managerial apparatus, and ability to marshal resources from a wide area. Nevertheless, the continuity and duration of the Manchay culture for a millennium are a clear demonstration of the resilience and flexibility of its social forms in the face of mega-El Niños and other disasters that must have occurred. In this respect, the Manchay culture's lack of centralization and hierarchy may have been an asset rather than an obstacle. The mobilization of labor for efforts like the monumental wall should not surprise us, since even greater projects were undertaken during the second millennium to obtain water through gravity canals. In fact, the creation of new canals was intimately linked to the establishment of the agricultural lands needed to support newly established social units and their public centers. Other corporate labor efforts were undertaken to obtain supernatural favor through temple construction.

The ability of the Manchay culture's subsistence economy to withstand short-term climatic disruptions is comprehensible, since its continued dependence on a range of maritime resources, hunting, and wild plants would have served the people well during an El Niño event. Moreover, the social institutions underlying the impressive public constructions of the Manchay culture would have been an asset in times of crisis. In times of emergency, the annual mobilization of public labor usually used to refurbish the U-shaped pyramid complexes could have been turned to repairing the relatively short canals that irrigated their fields and that would have been damaged by major El Niño events, or to renovate the monumental dam protecting the site.

As already noted, the construction technique, the masonry style, and the pattern of episodic renovations of the dam differ little from that used in the temple. In many respects, the challenge of building a long linear feature like the Manchay Bajo dam is analogous to the construction of a gravity canal. Contemporary communities construct and maintain canals without state intervention by dividing the required labor between the family units or communities that benefit from the irrigation water, with participation in the cooperative labor effort a prerequisite for continued community membership (i.e., access to land and water). Such cooperative labor practices have been documented for pre-Hispanic times, and may have been in place by the Initial Period (Burger 1992; Mosely 1992). Considering these factors, it is worth considering whether the pre-state societies of the Initial Period may have been as well as or, perhaps, even better equipped to deal with mega-El Niños than the more fragile complex societies of later times.

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Literature Cited

Benfer, R., and S. Meadors. 2002. Adaptaciones de la dieta humana a nuevos problemas y oportunidades en la costa central del Perú (1800–800 a.c.). *In* R. L. Burger and K. Makowski, eds., Arqueología del Valle de Lurín. Imprenta de la Pontificia Universidad Católica, Lima, Peru, in press.

Bennett, W., and J. Bird. 1960. Andean Culture History. American Museum of Natural History, New York.

Burger, R. 1985. Concluding remarks: Early Peruvian civilization and its relation to the Chavin Horizon, pp. 269–289. *In* C. Donnan, ed., Early Ceremonial Architecture in the Andes. Dumbarton Oaks Research Library and Collection, Washington, D.C.

———. 1992. Chavin and the Origins of Andean Civilization. Thames and Hudson, London.

Burger, R., and L. Salazar-Burger. 1991. The second season of investigations at the Initial Period center of Cardal, Peru. Journal of Field Archaeology, **18**(3): 275–296.

———. 1998. A sacred effigy from Mina Perdida and the unseen ceremonies of the Peruvian Formative. RES: Anthropology and Aesthetics, **33:** 28–53.

———. 2002. Investigaciones arqueológicas en Mina Perdida. *In* R. L. Burger and K. Makowski, eds., Arqueología del Valle de Lurín. Imprenta de la Pontificia Universidad Católica, Lima, Peru, in press.

Bushnell, G. 1957. Peru. Praeger, New York.

Davis, M. 1998. The Ecology of Fear. Metropolitan Books, New York.

Dulanto, J., L. Caceres, M. I. Velarde, and L. F. Villacorta. 2002. Investigaciones en Pampa Chica. *In* R. L. Burger and K. Makowski, eds., Arqueología del Valle de Lurín. Imprenta de la Pontificia Universidad de Católica, Lima, Peru, in press.

Lanning, E. 1967. Peru Before the Incas. Prentice-Hall, Englewood Cliffs, N.J.

Lumbreras, L. G. 1969. De los pueblos, las culturas y las artes del antiguo Perú. Francisco Mancloa Editores, Lima, Peru.

Mastalerz, K. 1999. Sedimentary Processes and Modifications of Unconsolidated Deposits in the Manchay Bajo Excavation Area. Unpublished report prepared for the Yale University Lurin Valley Archaeological Project.

Moore, J. D. 1991. Cultural responses to environmental catastrophes: Post-El Niño subsistence on the prehistoric north coast of Peru. Latin American Antiquity, **2**(1): 27–47.

Moseley, M. E. 1992. The Incas and Their Ancestors. Thames and Hudson, London.

Murphy, R. 1926. Oceanic and climatic phenomena along the west coast of South America during 1925. Geographical Review, **16:** 26–54.

Pozorski, S., and T. Pozorski. 1992. Early civilization in the Casma Valley, Peru. Antiquity, **66:** 845–870.

Richardson, J. B. III. 1994. People of the Andes. Smithsonian Press, Washington, D.C.

Rollins, H., J. Richardson III, and D. Sandweiss. 1986. The birth of El Niño: Geoarchaeological evidence and implications. Geoarchaeology, **1**(1): 3–15. John Wiley and Sons, New York.

Sandweiss, D., K. A. Maasch, J. B. Richardson III, and H. B. Rollins. 2001. Variation in Holocene El Niño frequencies: Climate records and cultural consequences in ancient Peru. Geology, **29**(7): 603–606.

Shady, R. 1997. La ciudad sagrada de Caral: Supe en los albores de la civilización en el Perú. UNMSM, Lima, Peru.

Silva, J., and R. García. 1997. Huachipa-Jicamarca: Cronología y desarrollo sociopolítico en el Rimac. Boletín del Instituto Frances de Estudios Andinos, **26**(2): 195–228.

Umlauf, M. 2002. Restos botánicos de Cardal durante el Período Inicial, Costa Central del Perú. *In* R. L. Burger and K. Makowski, eds., Arqueología del Valle de Lurín. Imprenta de la Pontificia Universidad Católica, Lima, Peru.

Wilson, D. 1981. Of maize and men: A critique of the maritime hypothesis of state origins on the coast of Peru. American Anthropologist, **83:** 93–120.

———. 1999. South Americans of the Past and Present. Westview Press, Boulder, Colorado.